Chapter 5. HAND/WRIST MUSCULOSKELETAL DISORDERS (CARPAL TUNNEL SYNDROME, TENDINITIS, AND HAND-ARM VIBRATION SYNDROME): EVIDENCE FOR WORK-RELATEDNESS

Musculoskeletal disorders (MSDs) of the hand/wrist region have been separated into three components for the purpose of this review: (a) Carpal Tunnel Syndrome (CTS), (b) Hand/Wrist Tendinitis, and (c) Hand-Arm Vibration Syndrome (HAVS). Each of these are described with regard to the evidence for causality between workplace risk factors and development of MSDs.

Chapter 5a. Carpal Tunnel Syndrome

SUMMARY

Over 30 epidemiologic studies have examined physical workplace factors and their relationship to carpal tunnel syndrome. Several studies fulfill the four epidemiologic criteria that were used in this review, and appropriately address important methodologic issues. The studies generally involved populations exposed to a combination of work factors, but a few assessed single work factors such as repetitive motions of the hand. We examined each of these studies, whether the findings were positive, negative, or equivocal, to evaluate the strength of work-relatedness using causal inference.

There is **evidence** of a positive association between highly repetitive work alone or in combination with other factors and carpal tunnel syndrome (CTS) based on currently available epidemiologic data. There is also **evidence** of a positive association between forceful work and CTS. There is **insufficient evidence** of an association between CTS and extreme postures. Individual variability in work methods among workers in similar jobs and the influence of differing anthropometry on posture are among the difficulties noted in measuring postural characteristics of jobs in field studies. Findings from laboratory-based studies of extreme postural factors support a positive association with CTS. There is **evidence** of a positive association between work involving hand/wrist vibration and CTS.

There is **strong evidence** of a positive association between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and CTS. Based on the epidemiologic studies reviewed above, especially those with quantitative evaluation of the risk factors, the evidence is clear that exposure to a combination of the job factors studied (repetition, force, posture, etc.) increases the risk for CTS. This is consistent with the evidence that is found in the biomechanical, physiological, and psychosocial literature. Epidemiologic surveillance data, both nationally and internationally, have also consistently indicated that the highest rates of CTS occur in occupations and job tasks with high work demands for intensive manual exertion - for example, in meatpackers, poultry processors, and automobile assembly workers.

INTRODUCTION

In 1988, CTS had an estimated population prevalence of 53 cases per 10,000 current workers [Tanaka 1997]. Twenty percent of these individuals reported absence from work because of CTS. In 1994, the Bureau of Labor Statistics (BLS) reported that the rate of CTS cases that result in "days away from work" was 4.8 cases per 10,000 workers. The agency also reported that the median number of days away from work for CTS was 30, which is even greater than the median reported for back pain cases [BLS 1995]. In 1993, the incidence rate (IR) for CTS workers' compensation cases was 31.7 cases per 10,000 workers; only a minority of these cases involved time off of work [Department of Labor and Industry, State of Washington 1997]. These data suggest that about 5 to 10 workers per 10,000 workers will miss work each year due to work-related CTS.

In recent years, the literature relating occupational factors to the development of CTS has been extensively reviewed by numerous authors [Moore 1992; Stock 1991; Gerr et al. 1991; Hagberg et al. 1992; Armstrong et al. 1993; Kuorinka et al. 1994; Viikari-Juntura 1995]. Most of these reviews reach a similar conclusion—work factors are one of the important causes of CTS. One review [Moore 1992] found the evidence more equivocal, but stated that the epidemiologic studies revealed a fairly consistent pattern of observations regarding the spectrum and relative frequency of CTS [among other musculoskeletal disorders (MSDs)] among jobs believed to be hazardous. The epidemiologic studies which form the basis for these reviews are outlined in Tables 5a-1 to 5a-4 of this chapter.

Thirty studies of occupational CTS are listed on Tables 5a-5. Twenty-one are cross-sectional studies, six are case-control, and three involve a longitudinal phase; all have been published since 1979. We included one surveillance study [Franklin 1991] because it has been included in many of the earlier reviews. The few earlier studies of CTS identified were clinical case series, or did not identify work place risk factors and were not included in the tables related to CTS.

OUTCOME AND EXPOSURE MEASURES

In four of 30 studies listed in Tables 5a-1 to 5a-4, CTS was assessed based on symptoms alone; in another nine studies, the case definition was based on a combination of symptoms and physical findings. Electrophysiological tests of nerve function were completed in 14 studies. Electrodiagnostic testing (nerve conduction studies) has been considered by some to be a requirement for a valid case definition of CTS, as is similarly used for a clinical diagnosis in individuals with CTS. A few studies which have looked at the relationship of occupational factors to CTS have used a health outcome based on electrodiagnostic testing alone [Nathan 1989; Schottland 1991; Radecki 1996.] However, some authors [Nilsson 1995; Werner et al. 1997] have discouraged the use of labeling workers as having "CTS" or "median nerve mononeuropathy" based on abnormal sensory nerve conduction alone (without symptoms). The reason for this view is illustrated in a recent prospective study by Werner et al. [1997]. On follow-up six to eighteen months after initial evaluation, they found that asymptomatic active workers with abnormal sensory median nerve function (by Nerve Conduction Studies [NCS]) were no more likely to develop symptoms consistent with CTS than those with normal nerve function. Studies which have used nerve conduction tests for epidemiologic field studies have employed a variety of evaluation methods and techniques [Nathan 1988, 1992; Bernard 1993; Osorio 1994]. Normal values for nerve conduction studies have also varied from laboratory to laboratory. NCS results have been found to vary with electrode placement, temperature, as well as age, height, finger circumference and wrist ratio [Stetson 1992], suggesting that "normal" values may need to be corrected for those factors.

Several epidemiologic studies have used a surveillance case definition of CTS based on symptoms in the median nerve distribution and abnormal physical examination findings using Phalen's test and Tinel's sign, and have not included NCS. Two recent studies [Bernard 1993; Atterbury 1996] looked at CTS diagnosis based on questionnaire and physical examination findings and its association with the "gold standard" of nerve conduction diagnosed median mononeuropathy. Both studies found statistically significant evidence to support the use of an epidemiologic CTS case definition based on symptoms and physical examination (not requiring NCS) for epidemiologic surveillance studies. Nathan [1992a] also found a strong relationship between symptoms and prolonged sensory median nerve conduction. (It is important to note here that a case definition used for epidemiologic purposes usually differs from one used for medical diagnosis and therapeutic intervention.)

Researchers have relied on a variety of methods to assess exposure to suspected occupational risk factors for CTS. These methods include direct measurement, observation, self-reports, and categorization by job titles. Most investigators agree that use of observational or direct measurement methods increases the quality (both the precision and accuracy) of ergonomic exposure assessments, but these methods also tend to be costly and time consuming. In general, misclassification errors tend to dilute the observed associations between disease and physical work load [Viikari-Juntura 1995].

REPETITION

Definition of Repetition for CTS

For our review, we identified studies that examined repetition or repetitive work for the hand and wrist for CTS as cyclical or repetitive work activities that involved either 1) repetitive hand/finger or wrist movements such as hand gripping or wrist extension/flexion, ulnar/radial deviation, and supination or pronation. Most of the studies that examined repetition or repetitive work as a risk factor for CTS had several concurrent or interacting physical work load factors. Therefore, repetitive work should be considered in this context, with repetition as only one exposure factor, accompanied by others such as force, extreme posture, and, less commonly, vibration.

Studies reporting on the Association of Repetition and CTS

Fifteen studies reported on the results of the association between repetition and CTS. Several studies in Table 5a-1 quantitatively measured [Moore 1994; Chiang 1990, 1993; Silverstein 1987] or observed [Stetson 1993; Nathan 1988, 1992; Barnhart 1991; Osorio 1994] and categorized repetitive hand and wrist movements in terms of: a) the frequency or duration of tasks pertaining to the hand/wrist, b) the ratio of work-time to recovery time, c) the percentage of the workday spent on repetitive activities, or d) the quantity of work performed in a given time. The rest of the studies generally used job titles or questionnaires to characterize exposure.

Studies meeting the four evaluation criteria

Four epidemiologic studies of the hand/wrist area addressed repetitiveness and CTS [Chiang et al. 1990, 1993; Moore et al. 1994; Silverstein et al. 1987] met the four criteria. Chiang et al. [1990] studied 207 workers from 2 frozen food processing plants. Investigators observed job tasks and divided them into low or high repetitiveness categories of wrist movement based on cycle time, as previously described by Silverstein et al. [1987]. Jobs were also classified according to whether or not workers' hands were exposed to cold work conditions. The resulting exposure groups were: Group 1 - Not Cold, Low Repetitiveness (mainly office staff and technicians); Group 2 - Cold Exposure or High Repetitiveness; and Group 3 - Cold Exposure and High Repetitiveness. CTS diagnosis was based on abnormal clinical examination and nerve conduction studies. Prevalence of CTS was 3% in Group 1, 15% in Group 2, and 37% in Group 3. Statistical modeling that also included gender, age, length of employment, and cold resulted in an odds ratio (OR) for CTS among those with highly repetitive jobs of 1.87 (p=0.02). The OR for CTS among those exposed to cold conditions and high repetitiveness was 3.32 (p=0.03). The authors cautioned that cold exposure may have at least partially acted as a proxy for forceful hand/wrist exertion in this study group.

Chiang et al. [1993] studied 207 workers from 8 fish processing factories in Taiwan. Jobs were divided into 3 groups based on levels of repetitiveness and force. The comparison group (low force/low repetitiveness) was managers, office staff, and skilled craftsmen (group 1). The fish-processing workers were divided into high repetitiveness or high force (group 2), and high force and high repetitiveness (group 3). Repetition of upper limb movements (not specifically the wrist) was defined based on observed cycle time [Silverstein et al. 1987]. CTS was defined on the basis of symptoms and positive physical examination findings, ruling out systemic diseases and injury. CTS prevalence for the overall study group was 14.5%. CTS prevalence increased from group 1, to group 2, and to group 3 (8.2%, 15.3%, and 28.6%, respectively), a statistically significant trend (p<0.01). Repetitiveness alone was not a significant predictor of CTS (OR=1.1). Statistical modeling showed that women in this study group had a higher prevalence of CTS than men (OR=2.6, 95% confidence interval [CI] 1.3-5.2). Because the proportion of women varied by exposure group (48%, 75%, and 79% from group 1 to 3), further analyses were limited to females. The OR for repetitiveness was 1.5 (95% CI 0.8-2.8), controlling for oral contraceptive use and force.

Moore [1994] evaluated 32 jobs in a pork processing plant and then reviewed past OSHA illness and injury logs and plant medical records for CTS cases in these job categories. A CTS case required the recording of suggestive symptoms (numbness and tingling) combined with electrodiagnostic confirmation (as reported by the attending electromyographers) of a case. IRs were calculated using the full-time equivalent number of hours worked reported on the logs. The exact number of workers was not reported. Exposure assessment included videotape analysis of job tasks for repetitiveness and awkward postures. The force measure was an estimate of the percent maximum voluntary contraction (%MVC) based on weight of tools, and parts and population strength data adjusted for extreme posture or speed. Jobs were then categorized as hazardous or safe (for all upper extremity MSDs, not for CTS), based on exposure data and the judgement of the investigators. The hazardous jobs had a relative risk (RR) for CTS of 2.8 (95% CI 0.2-36.7) compared to the safe jobs. Due to the lack of data from individual workers, the study was unable to control for common confounders. Potential for survivor effect (79% of the workforce was laid off the year prior to the study), a limited latency period (8-32 months), and the potential for incomplete case ascertainment (underreporting is known to be a problem with OSHA illness and injury logs) limit confidence in this estimate. This study did not specifically address the relationship between repetitiveness and CTS. No significant association was identified between repetitiveness and the grouped "upper extremity musculoskeletal disorders," but there was very little variability in repetitiveness (31 of the 32 jobs had a cycle time less than 30 seconds).

Silverstein et al. [1987] studied 652 workers in 39 jobs from 7 different plants (electronics, appliance, apparel, and bearing manufacturing; metal casting, and an iron foundry). Investigators divided jobs into high or low repetitiveness categories, based on analysis of videotaped job tasks of 3 representative workers in each job. High repetitiveness was defined as cycle time less than 30 seconds or at least 50% of the work cycle spent performing the same fundamental movements. Jobs were also divided into high or low force categories based on EMGs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job. High force was defined as a mean adjusted force > 6 kg. Jobs were then classified into 4 groups: low force/low repetitiveness, high force/low repetitiveness, low force/high repetitiveness, and high force/high repetitiveness. Fourteen cases (2.1% prevalence) of CTS were diagnosed based on standardized physical examinations and structured interviews.

The OR for CTS in highly repetitive jobs compared to low repetitive jobs, irrespective of force, was 5.5 ($p<0.05$) in a statistical model that also included age, gender, years on the job, and plant. The OR for CTS in jobs with combined exposures to high force and high repetition was 15.5 ($p<0.05$), compared to jobs with low force and low repetition. Age, gender, plant, years on the job, hormonal status, prior health history, and recreational activities were analyzed and determined not to confound the associations identified.

Studies Meeting at Least One Criteria
Fourteen additional studies met at least one of the criteria.

Barnhart et al. [1991] studied ski manufacturing workers categorized as having repetitive or nonrepetitive jobs based on observational exposure methods for hand/wrist exposure. The participation rate for this study was below 70%. Three different case definitions were used for CTS based on symptoms, physical exam findings, and NCS using the mean median-ulnar difference in each group. Each case definition used the NCS results. The authors reported a significant prevalence ratio (PR) of 2.3 for the mean median-ulnar sensory latency nerve difference among those in repetitive jobs compared to those in non-repetitive jobs. However, the difference was found in the ulnar rather than in the median nerve. The median nerve latencies were not statistically different between the two groups.

Baron et al. [1991] studied CTS in 124 grocery store checkers and 157 other grocery store workers who were not checkers. The CTS case definition required symptoms that met pre-determined criteria on a standardized questionnaire and physical examinations. The OR for CTS among checkers was 3.7 (95% CI 0.7-16.7), in a model that included age, hobbies, second jobs, systemic disease, and obesity. Participation rates at the work sites were higher among the exposed group (checkers: 85% participation, non-checkers: 55% participation). After telephone interviews in which 85% of the non-checkers completed questionnaires, investigators reported that the proportion of non-checkers meeting the case definition did not increase.

Cannon et al. [1981] in a case-control study of aircraft engine workers did not find a significant association with the performance of repetitive motion tasks (OR=2.1, 95%CI 0.9-5.3), but found a significant association with self-reported use of vibrating hand tools, history of gynecologic surgery, and an inverse relationship with years on the job. One must assume from the article that "repetitive motion tasks" were defined by job title. The diagnosis of CTS was based on medical and workers' compensation records.

In English et al.'s [1995] case-control study of upper limb disorders diagnosed in orthopedic clinics, the case series included 171 cases of CTS and 996 controls. Exposure was based on self-reports; repetitiveness was defined as a motion occurring more than once per minute. The logistic regression model of CTS found significant associations with height (negative), weight (positive), presentation at the clinic as a result of an accident (negative) and two occupational factors: (1) uninterrupted shoulder rotation with elevated arm [OR of 1.8 (1.2, 2.8)] and (2) protection from repeated finger tapping [OR of 0.4 (0.2, 0.7)]. The authors note that the latter observation presented "difficulties of interpretation." Limitations of this study concern the lack of exposure assessment for repetition, and the questionable reliability for reported limb movements as an accurate measure of repetition.

Feldman [1987] studied electronic workers at a large manufacturing firm using a questionnaire survey and biomechanical job analysis. Four work areas with 84 workers were identified as "high risk" with highly repetitive and forceful tasks. Workers in these high risk areas had physical examinations and NCS. Sixty-two workers from the high risk area had repeat NCS one year later. Comparing these high risk workers to the others, one can calculate ORs for symptoms of numbness and tingling [OR= 2.2 ($p < 0.05$)] and a positive Phalen's sign [2.7 ($p < 0.05$)]. Longitudinal NCS of workers in the high risk area showed significant worsening in the median motor latency and sensory conduction velocity in the left hand, and motor changes over a year's period, which the authors attributed to work exposure. A limitation of this study concerns inadequate exposure information about the extent of worker exposure to repetitive and forceful work.

McCormack et al. [1990] studied 1,579 textile production workers and compared them to 468 other non-office workers, a comparison group that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers were divided into four broad job categories based on similarity of upper extremity exertions. No formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. CTS was diagnosed using predetermined clinical criteria. The severity of cases was also reported as mild, moderate or severe. The overall prevalence for CTS was 1.1%, with 0.7% in boarding, 1.2% in sewing, 0.9% in knitting, 0.5% in packaging/folding, and 1.3% in the comparison group. None of the differences was statistically significant. A statistical model that also included age, gender, race, and years of employment showed that CTS occurred more often among women in this study ($p<0.05$). Interpretation of these data, especially with a low prevalence disorder like CTS, is difficult since gender varied with job (94% of boarding workers were female, compared to 56% in the comparison group), and the comparison group (machine maintenance workers, transportation workers, cleaners and sweepers) may have also been exposed to upper extremity exertions. Interactions among potential confounders were not addressed, but they are suspected because of significant associations between race and three MSDs.

Morgenstern et al. [1991] mailed questionnaires to 1,345 union grocery checkers and a general population group. Exposure was based on self-reported time working as a checker. Symptoms of CTS were significantly associated with age and the use of diuretics, and nonsignificantly associated with average hours worked per week, and years worked as a checker. A positive CTS outcome was based on the presence of all four symptoms: pain in the hands or wrist, nocturnal pain, tingling in the hands or fingers, or numbness. The estimated attributable fraction of CTS symptoms to working as a checker was about 60%, using both a general population comparison group and a low exposed checker group. The limitations of this study are: 1) the use of an overly sensitive health outcome measure, for example, 32% of the surveyed population reported numbness; and 2) the use of self-reported exposure.

Nathan et al. [1988] studied median nerve conduction of 471 randomly selected workers from four industries (steel mill, meat/food packaging, electronics, and plastics manufacturing). Median nerve sensory latency values were adjusted for age for statistical analyses. Thirty-nine percent of the study subjects had impaired sensory nerve conduction, or "slowing" of the median nerve. The five exposure groups were defined as follows: Group 1 is very low force, low repetition (VLF/LR); Group 2 is low force, very high repetition (LF/VHR); Group 3 is moderate force, moderate repetition (MF/MR); Group 4 is high force/moderate repetition (HF/MR); and Group 5 is very high force/high repetition (VHF/HR). There was no significant difference between Group 1 and Group 2, the groups that had the greatest differences in repetition. The authors reported a significantly higher number of subjects with median nerve slowing in Group 5 (VHF/HR) compared to Group 1 (VLF/LR), but not in other groups, using a statistical method described as a "pairwise unplanned simultaneous test procedure" [Sokal and Rohlf 1981]. The authors also reported that when individual hands were the basis of calculations rather than subjects, Group 3 had a significantly higher prevalence of median nerve slowing. Calculations of the data using PRs and chi-squares [Kleinbaum et al. 1982] result in significantly higher prevalences of median nerve slowing in each of Groups 3, 4, and 5, (moderate to high repetition, with moderate to very high force) compared to Group 1 (VLR/LF). PRs are 1.9 (95% CI 1.3-2.7), 1.7 (95% CI 1.1-2.5), and 2.0 (95% CI 1.1-3.4), for Groups 3, 4, and 5, respectively. A conservative (Bonferroni) adjustment of the significance level to 0.0125 for multiple comparisons [Kleinbaum et al. 1988] would result in Group 5 no longer being statistically significantly different from

Group 1 (p=0.019), but Group 4 (p=0.009), and Group 3 (p=0.000) remain statistically significantly higher than Group 1 in prevalence of median nerve slowing.

In 1992a, Nathan et al. reported on a follow-up evaluation in the same study group. Sixty-seven percent of the original study subjects were included. Hands (630), rather than subjects, were the basis of analysis in this study. Novice workers (those employed less than 2 years in 1984) were less likely to return than non-novice workers (56% compared to 69%, p=.004). Maximum latency differences in median nerve sensory conduction were determined as in the Nathan et al. 1984 study. The authors state that there was no significant difference in the prevalence of median nerve slowing between any of the exposure categories in Nathan et al. 1989, using the same statistical method described in the Nathan et al. 1988 study. However, calculations using common statistical methods result in the following PRs for slowing: Group 3 - 1.5 (95% CI 1.0-2.2), Group 4 - 1.4 (95% CI 0.9-2.1), and Group 5 - 1.0 (95% CI 0.5-2.2), compared to Group 1. Group 5 had the same prevalence of slowing (18%) as Group 1 in 1989. In 1984 the prevalence of slowing was 29% in Group 5, and 15% in Group 1. The drop in prevalence of median nerve slowing in Group 5 between 1984 and 1989 might be explained by the higher drop-out rate among cases in Group 5 compared to Group 1 (PR=2.9, 95% CI 1.3-6.6). This was not addressed by the authors.

Osorio et al. [1994] studied 56 supermarket workers. Exposure to repetitive and forceful wrist motions was rated as high, moderate, or low, following observation of job tasks. The CTS case definition was based on symptoms and nerve conduction studies. CTS-like symptoms occurred more often (OR=8.3, 95% CI 2.6-26.4) among workers in the high exposure group compared to the low exposed group. The odds of meeting the symptom and NCS-based CTS case definition among the high exposure group were 6.7 (95% CI 0.8-52.9), compared to the low exposure group.

Punnett et al. [1985] compared the symptoms and physical findings of CTS in 162 women garment workers and 76 women hospital workers such as nurses, laboratory technicians, and laundry workers. Eighty-six percent of the garment workers were sewing machine operators and finishers (sewing and trimming by hand). The sewing machine operators were described as using highly repetitive, low force wrist and finger motions, whereas finishing work also involved shoulder and elbow motions. The exposed garment workers probably had more repetitive jobs than most of the hospital workers. CTS symptoms occurred more often among the garment workers (OR=2.7, 95% CI 1.2-7.6) compared to the hospital workers. There was a low participation rate (40%) among the hospital workers.

Schottland et al. [1991] carried out a comparison of NCS findings in poultry workers and job applicants as referents. No exposure assessment was performed, and applicants were not excluded if they had prior employment in the plant. Results indicated that the right median nerve sensory latency was significantly longer in 66 female poultry workers compared to 41 female job applicants. In these two groups of women there were less pronounced differences in the left median sensory latency. The latencies in the 27 male poultry workers did not differ significantly from the 44 male job applicants, although the power calculations presented in the paper noted limited power to detect differences among male participants. The OR for percentage of female poultry workers who exceeded the criteria value for the right median sensory latency is 2.86 (1.1, 7.9). The major limitations of this study are the absence of detailed information on exposure, and the inclusion of former poultry workers into the applicant group, as well as the inadequate sample size, and the personal characteristics of these workers. This study found a significant association between highly repetitive, highly forceful work and abnormal NSC consistent with CTS. It does not allow analysis of repetition alone.

Stetson et al. [1993] used measurements of sensory nerve conduction velocity of the median nerve as indicators of nerve impairment or CTS; clinical examination results were not reported in this article. Three groups were studied: a reference group of 105 workers without occupational exposure to highly forceful or repetitive hand exertions, 103 industrial workers with hand/wrist symptoms, and 137 asymptomatic industrial workers. Exposure was assessed with a checklist by trained workers. Factors considered included repetitiveness (Silverstein criteria), force defined by the weight of an object that is carried or held, localized mechanical stress, and posture. Exposure assessments were available on 80% of the industrial workers. Most of the industrial workers were on repetitive jobs (76%), a minority carried more than ten pounds some of the time (32%), and gripped more than six pounds at least some of the time (44%). The analysis controlled for several confounders including age, gender, finger circumference, height, weight, and a square-shaped wrist. In the comparison of the asymptomatic to symptomatic industrial workers, the mean exposure for the symptomatic industrial workers was nonsignificantly slightly greater for all exposure factors except for repetitiveness. The median sensory amplitudes were significantly smaller ($p < 0.01$) and latencies longer ($p < 0.05$) for industrial workers with exposure to high grip forces compared with those without. Mean sensory amplitudes were significantly smaller ($p < 0.05$) and motor and sensory latencies were significantly longer ($p < 0.01$) in the industrial asymptomatic workers compared to the control group. These findings for the motor latencies are similar to Feldman et al. [1987]. Since most of the industrial workers were exposed to repetitive work, it is not clear whether this study population allowed a comparison between repetitive and non-repetitive work. Overall this study suggests that repetitive work combined with other risk factors is associated with slowing of median nerve conduction.

Weislander et al.'s [1989] case-control study used self-reported information collected via telephone interview about the duration of exposure (number of years and hours per week) to several work attributes including repetitive work. Definitions for these work attributes were not provided. Three categories of duration of exposure were defined for each attribute (<1 year, 1-20 years, and >20 years), but the asymmetry of the categories was not explained. A significant OR for reporting repetitive movements of the wrist comparing CTS patients to hospital referents (OR=4.6) and general population referents (OR=9.6) was reported, but only among those employed greater than 20 years. Those employed from 1-20 years compared to the referent population had elevated ORs for repetitive movements of the wrist (1.5 for CTS patients compared to hospital referents, and 2.3 compared to population referents), but these were not significant. Jobs with increasing numbers of work risk factors gave increasing ORs (from 1.7 to 7.1) among CTS cases when compared to referents; these were statistically significant when there were two or more risk factors. Given the limited quality of the exposure data and findings (repetition is a significant risk factor only after 20 years of exposure), this is only suggestive of a relationship between repetition alone and CTS.

Studies not meeting any of the criteria

Liss et al. [1995] conducted a mail survey concerning CTS among 2124 Ontario dental hygienists compared to 305 dental assistants who do not scale teeth. Both groups had a low response rate (50%). The age adjusted OR was 5.2 [95% CI 0.9-32] for being told by a physician that you had CTS and 3.7 [95% CI 1.1-1.9] using a questionnaire-based definition of CTS. The major limitations of this study are the low participation rate, the lack of a detailed exposure assessment for repetitiveness, and self-reported health outcome.

Strength of Association - Repetition and CTS

Three of the four studies that met all four criteria evaluated the effect of repetitiveness alone on CTS: Chiang et al. [1990], Silverstein et al. [1987], and Chiang et al. [1993].

Chiang et al. [1990] reported an OR of 1.9 ($p<0.05$) for CTS among those with highly repetitive jobs. The OR for CTS among those exposed to high repetitiveness and cold was 3.32 ($p<0.05$). The additional effect attributed to cold may be at least partially explained by forceful motions among workers who were also exposed to cold. Force was not evaluated in this study.

Silverstein et al. [1987] reported an OR of 5.5 ($p<0.05$) for repetition as a single predictor of CTS. Among workers exposed to high repetition and high force, the OR was 15.5 ($p<0.05$).

Chiang et al. [1993] reported a significant trend of increasing prevalence of CTS with increasing exposure to repetition and/or force (8.2%, 15.3%, and 28.6%, $p<0.05$). Repetition (of the whole upper limb, not the wrist) alone did not significantly predict CTS (OR=1.1).

In summary, three studies that met all four criteria reported ORs for CTS associated with repetition. The statistically significant ORs for CTS attributed to repetition alone ranged from 1.9 to 5.5. The statistically significant ORs for CTS attributed to repetition in combination with force or cold ranged from 3.3 to 15.5. Gender, age, and other potential confounders were addressed and are unlikely to account for the associations reported.

Five other studies observed job tasks, then grouped them into categories according to estimated levels of repetitiveness combined with other risk factors [Feldman et al. 1987; Moore and Garg 1994; Nathan et al. 1988, 1992; and Osorio et al. 1994]. CTS case definitions reported here required more than symptom-defined criteria. Moore and Garg [1994] reviewed medical records; Nathan et al. [1988] and Osorio [performed nerve conduction studies.

Feldman et al. [1987] reported an OR of 2.7 ($p<0.05$) for a positive Phalen's test among workers in high exposure jobs, compared to low exposure jobs.

Moore and Garg [1994] reported an OR of 2.8 (0.2, 36.7) for CTS among workers in "hazardous" jobs compared to workers in "non-hazardous" jobs.

Nathan et al.'s [1988] data result in PRs ratios for four groups with varying levels of repetitiveness and force from very low (VL) to very high (VH), compared to a very low force, low repetition group (VLF/LR):
LF/VHR versus VLF/LR: 1.0 (0.5, 2.0)
MF/MR versus VLF/LR: 1.9 (1.3, 2.7)
HF/MR versus VLF/LR: 1.7 (1.1, 2.5)
VHF/HR versus VLF/LR: 2.0 (1.1, 3.4).

Nathan et al. [1992] data, a 5-year follow-up of the 1988 study, result in PRs for the following groups:
LF/VHR versus VLF/LR: 1.0 (0.6, 1.9)
MF/MR versus VLF/LR: 1.5 (1.0, 2.2)
HF/MR versus VLF/LR: 1.4 (0.9, 2.1)
VHF/HR versus VLF/LR: 1.0 (0.5, 2.2).

Osorio et al. [1994] reported an OR of 6.7 (0.8, 52.9) for CTS among workers in high exposure jobs, compared to workers in low exposure jobs. Using a symptom-based case definition, the OR for the same comparison groups was 8.3 (2.6, 26.4).

To summarize, three of the five studies reviewed resulted in statistically significant positive findings for CTS associated with combined exposures. Feldman et al. [1987] reported an elevated OR for CTS with high combined exposure. Nathan et al.'s 1988 data resulted in elevated PRs for CTS among the three highest combined exposure groups. Nathan et al.'s 1992 data resulted in elevated PRs for CTS among two of the three highest combined exposure groups.

The following studies used job title or job category to represent exposure to repetitiveness combined with other exposures and defined CTS based on physical examination or nerve conduction studies: Baron et al. [1990], McCormack et al. [1990], Punnett et al. [1985], and Schottland et al. [1991].

Baron et al. [1990] reported an OR of 3.7 (95% CI 0.7-16.7) for CTS, defined by symptoms and physical examination, among grocery checkers compared to other grocery workers.

McCormack et al. [1990] reported the following OR s for CTS among workers in each of four broad job categories that were considered exposed, compared to a comparison group of maintenance workers and cleaners that was considered to have low exposure:
Boarding vs. Low: 0.5 (95% CI 0.1-2.9)
Sewing vs. Low: 0.9 (95% CI 0.3-2.9)
Packaging vs. Low: 0.4 (95% CI 0.0-2.4)
Knitting vs. Low: 0.6 (95% CI 0.1-3.1)

Punnett et al. [1985] reported an OR of 2.7 (95% CI 1.2-7.6) for CTS among garment workers vs. hospital workers.

Schottland et al. [1991] reported an OR of 2.86 (95% CI 1.1-7.9) for prolonged right median sensory latency among female poultry workers, compared to female applicants for the same jobs. No significant differences were identified among males.

In summary, two of the four studies reviewed above reported significantly elevated ORs for CTS or median sensory nerve conduction slowing.

Wieslander et al. [1989] reported an OR for CTS (surgical cases, confirmed by NCS) of 2.7 (95% CI 1.3-5.4) among those with self-reported exposure to repetitive wrist movement >20 years, compared to hospital referents, and 4.5 (95% CI 2.0-10.4), compared to population referents. Significant OR s for CTS among those with combined job risk factors ranged from 3.3 to 7.1.

The remaining two studies relied on self-reported symptoms and self-reported exposures from mail (Morgenstern et al. [1991]) or telephone surveys (Liss et al. [1995]) . Data quality and response rates limit interpretation of findings.

In conclusion, among the studies that measured repetition alone, there is evidence that repetition is positively associated with CTS. The majority of studies provide evidence of a stronger positive association between repetition combined with other job risk factors and CTS.

Temporal Relationship: Repetition and CTS

The question of which occurs first, exposure or disease, can be addressed most directly in prospective studies. However, study limitations such as survivor bias can cloud the interpretation of findings. In our analysis of Nathan et al.'s 1992 data, 2 of 3 groups that were exposed to forceful hand/wrist exertions were more likely to have median nerve slowing, when nerve conduction testing was repeated 5 years later. The highest exposure group had the same prevalence of slowing as the lowest exposure group in 1989, whereas they had a higher prevalence rate in 1984. As discussed above, this apparent decrease in prevalence over 5 years can probably be explained by a higher drop-out rate among cases in the highest exposure group, compared to the lowest exposure group. These interpretations of the data differ from those of the authors. Further study is needed to clarify these issues. However, to our knowledge, there is no evidence demonstrating that those with CTS would be more likely to be hired in jobs that involve high exposure to repetitive hand/wrist exertions and combined job risk factors, compared to those without CTS. In fact, employment practices tend to exclude new workers with CTS from jobs that require repetitive and intensive hand/wrist exertion.

Feldman et al. [1987] reported longer median motor (but not sensory) latencies among workers with combined exposure to hand/wrist exertion, compared to nerve conduction findings in the same group one year earlier.

Cross-sectional studies provide evidence that exposure occurred before CTS, by using case definitions that exclude pre-existing cases, and by excluding recently hired workers from the study. The studies that provide evidence that repetitive and combined job exposures are associated with CTS followed these practices, therefore the associations identified cannot be explained by disease occurring before exposure.

Consistency in Association for Repetition and CTS

One study [English et al. 1995] reported a statistically significant negative association between repetitive work and CTS. The specific exposure was self-reported repeated finger tapping; the investigators stated that they had difficulty interpreting this finding. All of the other statistically significant findings pointed to a positive association between repetitive work and CTS. The non-significant estimates of RR were also mostly greater than one.

Coherence of Evidence for Repetition

One of the most plausible ways that repetitive hand activities may be associated with CTS is thoroughly causing a substantial increase in the pressure in the carpal tunnel. This in turn can initiate a process which results in either reversible or irreversible damage to the median nerve [Rempel 1995]. The increase in pressure, if it is of sufficient duration and intensity, may reduce the flow of blood in the epineural venules. If prolonged, this reduction in flow may affect flow in the capillary circulation, resulting in greater vascular permeability and endoneural and synovial edema. Because of the structure of the median nerve and the carpal tunnel, this increase in fluid and resulting increase in pressure may persist for a long period of time. If the edema becomes chronic, then it may trigger a fibrosis which damages the function of the nerve. The interplay between acute increases in pressure and chronic changes to the nerve could partially explain why there is not stronger correlation between symptoms of CTS and slowing of the median nerve. Both symptoms and slowing of the median nerve are likely to have both acute and chronic components in many cases of CTS.

The work determinants of pressure in the carpal tunnel are wrist posture and load on the tendons in the carpal tunnel. For example, the normal resting pressure in the carpal tunnel with the wrist in a neutral posture is about 5 millimeters of mercury (mmHg), typing with the wrist in 45° of extension can result in an acute pressure of 60 mmHg. Substantial load on the fingertip with the wrist in a neutral posture can increase the pressure to 50 mmHg. A parabolic relationship between wrist posture and pressure in the carpal tunnel has been found. In laboratory studies of normal subjects, elevated carpal tunnel pressures quickly return to normal once the repetitive activity stops; patients with CTS take a long time for the pressure to return to their baseline values. One of the supporting observations for this model is that at surgery for CTS, edema and vascular sclerosis (fibrosis due to ischemia) are common [Rempel et al. 1995].

This model of the etiology of work related CTS is consistent with two observations from the epidemiological literature. First, it illustrates why both work and non-work factors such as obesity may be important because anything that increases pressure in the carpal tunnel may contribute to CTS. Second, it explains why repetitiveness independent of wrist posture and load on the flexor tendons may not be a major risk factor for CTS.

Exposure-Response Relationship for Repetition

Evidence of an exposure-response relationship is provided by studies that show a correlation between the level or duration of exposure and either the number of cases, the illness severity, or the time to onset of the illness. Silverstein et al. [1987] showed an increasing prevalence of CTS signs and symptoms among industrial workers exposed to increasing levels of repetition and forceful exertion. This relationship was not seen when repetition alone was assessed. Similar findings on an exposure-response relationship were reported by Chiang et al. [1993], Osorio et al. [1994], Wieslander et al. [1989], and by Stock [1991] in her reanalysis of the Nathan et al. [1988] data.

Morgenstern et al. [1991] and Baron et al. [1991] reported increased prevalence of CTS with increasing length of time working as a grocery cashier.

Conclusions Regarding Repetition

Based on the epidemiologic studies noted above, especially those with quantitative evaluation of repetitive work, the strength of association for CTS and repetition has been shown to be ranging from an OR of 2 to 15. The higher ORs are found when contrasting highly repetitive jobs to low repetitive jobs, and when repetition occurred in combination with high levels of forceful exertion. Those studies with certain epidemiologic limitations have also been fairly consistent in showing a relationship between repetition and CTS. The evidence from those studies which defined CTS based on symptoms, physical findings, and NCS is limited, due to the variety of methods used [Nathan 1988; Stetson 1993; Barnhart 1993].

There is **evidence** of a positive association between highly repetitive work alone and CTS. There is **strong evidence** of a positive association between highly repetitive work in combination with other job factors and CTS, based on currently available epidemiologic data.

FORCE AND CTS [TABLE 5b-2]:

Definition of force for CTS:
The studies reviewed in this section determined hand/wrist force exposure by a variety of methods. Some investigators [Armstrong and Chaffin 1979, Chiang et al. 1993, Silverstein et al. 1987] measured force by EMGs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job; jobs were then divided into low or high categories if the average force was above or below a cutoff point. Moore and Garg [1994] estimated force as percent maximum voluntary contraction (%MVC), based on weight of tools and parts and population strength data, adjusted for extreme posture or speed. Jobs were then predicted to be either hazardous or safe (for any upper extremity musculoskeletal disorder), based on exposure data and judgement. Stetson et al. [1993] estimated manipulation forces based on weights of tools and parts and systematically recorded observations of one or more workers on each job. Jobs were then ranked according to grip force cutoffs. Nathan et al. [1988, 1992] and Osorio et al. [1994] estimated relative levels of force (e.g., low, moderate, high) after observation of job tasks. McCormick et al. [1990] grouped jobs into broad job categories based on similarity of observed job tasks; one job group (boarding) required forceful hand/wrist exertions. Baron et al. [1988] and Punnett et al. [1985] used job title as a surrogate for exposure to forceful hand/wrist exertions.

Much of the epidemiologic data on CTS and force overlaps with those studies discussed in the above section on repetition. Repetitive work is frequently performed in combination with external forces, and much of the epidemiologic literature has combined these two factors when determining association with CTS.

Studies reporting on the Association of Force and CTS

Ten studies reported results on the association between force and CTS. The epidemiologic studies that addressed forceful work and CTS tended to compare working groups by classifying them into broad categories based on estimates of the forcefulness of hand/wrist exertions in combination with estimated repetitiveness. In most studies the exposure classification was an ordinal rating (e.g., low, moderate, or high); in some studies job categories or titles were used as surrogates for exposure to force exertions.

Studies meeting the four evaluation criteria Studies reporting on the Association of Force and CTS

Three studies that evaluated the relationship between forceful hand/wrist exertion and CTS met all four criteria: Chiang et al. [1993], Silverstein et al. [1987] and Stetson et al. [1993]. Chiang et al. [1993] studied 207 workers from 8 fish-processing factories in Taiwan. Jobs were divided into 3 groups based on levels of force and repetitiveness. The comparison group (low force/low repetitiveness) was managers, office staff, and skilled craftsmen. The fish-processing workers were divided into high force **or** high repetitiveness (group 2), and high force **and** high repetitiveness (group 3). Hand force requirements of jobs were estimated by electromyographs of forearm flexor muscles of a representative worker from each group performing usual job tasks. High force was defined as an average hand force of >3 kg Repetition of the upper limb (not specifically the wrist) was defined based on observed cycle time (Silverstein et al. [1987]). CTS was defined on the basis of symptoms and positive physical examination findings, ruling out systemic diseases and injury. CTS prevalence for the overall study group was 14.5%. CTS prevalence increased from group 1 to group 3 (8.2%, 15.3%, and 28.6%), a statistically significant trend p<0.01). Statistical modeling showed that women in this study group had a higher prevalence of CTS than men (OR=2.6, 95% CI 1.3-5.2). Force also significantly predicted CTS (OR=1.8, 95% CI 1.1-2.9), but not repetitiveness. Because the proportion of women varied by exposure group (48%, 75%, and 79% from group 1 to 3), the possibility of an interaction between gender and job exposure exists, but this was not statistically examined. In an analysis limited to females, the 2 significant predictors of CTS were oral contraceptive use (OR=2.0, 95% CI 1.2-5.4), and force (OR=1.6, 95% CI 1.1-3.0). Concern over interpretation of these findings is raised because oral contraceptive use varies with age, and age may vary with job exposures. These potential interactions were not examined, and women's ages by job group were not reported.

Silverstein et al. [1987] measured force by electromyographs of representative workers' forearm flexor muscles while they performed their usual tasks. EMG measurements were averaged within each work group to characterize the force requirements of the job; jobs were then divided into high or low categories if the mean adjusted force was above or below 6 kg. Jobs were then classified into 4 groups that also accounted for repetitiveness: low force/low repetitiveness, high force/low repetitiveness, low force/high repetitiveness, and high force/high repetitiveness. Fourteen cases (2.1% prevalence) of CTS were diagnosed based on standardized physical examinations and structured interviews.

The OR for CTS in high force jobs compared to low force jobs, irrespective of repetitiveness, was 2.9 ($p>0.05$). The OR for CTS in jobs with combined exposures to high force and high repetition was 14.3 ($p<0.05$), compared to jobs with low force and low repetition. Age, gender, plant, years on the job, hormonal status, prior health history, and recreational activities were analyzed and determined not to confound the associations identified.

Stetson et al. [1993] conducted nerve conduction studies on 105 administrative and professional workers, and 240 automotive workers. Hand/wrist forces were estimated based on weights of tools and parts and systematically recorded observations of one or more workers on each job. Jobs were then ranked according to grip force cutoffs: <6 lbs, >6 lbs, >10 lbs. Median nerve measures differed among the groups: Index finger sensory amplitudes were lower and distal sensory latencies were longer among automotive workers in jobs requiring grip force >6 lbs and >10 lbs, compared to those requiring less than 6 lbs. ($p<0.05$ for all). At the wrist, median sensory amplitudes were also lower and distal median sensory latencies were also longer among the >6 lb, and the >10 lb exposure groups ($p<0.05$ for 3 of 4 differences). Age, height, and finger circumference were included in statistical models. The automotive workers were then divided into two groups, symptomatic (n=103) and asymptomatic (n=137), based on whether or not they met standard interview criteria for CTS symptoms. When comparisons were made to the administrative and professional workers, fifteen of sixteen measures of median and ulnar nerve function showed lower amplitudes and longer latencies ($p<0.05$) among the asymptomatic automotive workers; differences were greater between the symptomatic automotive workers and the white collar workers. The symptomatic automotive workers had lower amplitudes and longer latencies for 5 of 6 median sensory measures ($p<0.05$), compared to the asymptomatic automotive workers; there were no significant differences in ulnar nerve function between these two groups. To summarize the results of this study, unexposed white collar workers had "healthier" median and ulnar nerves, compared to automotive workers. Asymptomatic automotive workers had "healthier" median nerves than automotive workers with CTS symptoms, but there were no differences between these 2 groups in ulnar nerve function, suggesting that the case definition was specific for CTS.

Studies Meeting at Least One Criteria

Baron et al. [1991] studied CTS in 124 grocery store checkers and 157 other grocery store workers who were not checkers. The CTS case definition required symptoms that met pre-determined criteria on a standardized questionnaire. Physical examinations were also performed, but participation rates at the work sites were higher among the exposed group (checkers:

85% participation, non-checkers: 55% participation). Telephone interviews to non-checkers resulted in questionnaire completion by 85% of the non-checkers. Based on a questionnaire case definition, the OR for CTS among checkers was 3.7 (95% CI 0.7-16.7), in a model that included age, hobbies, second jobs, systemic disease, and obesity.

McCormack et al. [1990] studied 1,579 textile production workers compared to 468 other non-office workers, a comparison group that included machine maintenance workers, transportation workers, cleaners, and sweepers. The textile production workers were divided into four broad job categories based on similarity of upper extremity exertions. The Boarding group required the most physical exertion. No formal exposure assessment was conducted. Health assessment included a questionnaire and screening physical examination followed by a diagnostic physical examination. Carpal tunnel syndrome was diagnosed using predetermined clinical criteria. The severity of cases was also reported as mild, moderate or severe. The overall prevalence for CTS was 1.1%, with 0.7% in Boarding, 1.2% in Sewing, 0.9% in Knitting, 0.5% in Packaging/Folding, and 1.3% in the comparison group. None of the differences were statistically significant. A statistical model that also included age, gender, race, and years of employment showed that CTS occurred more often among women in this study ($p<0.05$). Interpretation of these data, especially with a low prevalence disorder like carpal tunnel syndrome, is difficult since gender varied with job (e.g., 94% of Boarding workers were female, compared to 56% in the comparison group), and the comparison group may have also been exposed to upper extremity exertions (machine maintenance workers, transportation workers, cleaners and sweepers). Interactions among potential confounders were not addressed, but they are suspected because of significant associations between race and three musculoskeletal disorders.

Moore et al. [1994] evaluated 32 jobs in a pork processing plant and then reviewed past OSHA 200 logs and plant medical records for CTS cases in these job categories. IRs were calculated using the full-time equivalent (FTEs) number of hours worked as reported on the logs . The exact number of workers was not reported. Exposure assessment included videotape analysis of job tasks for repetitiveness and awkward postures. The force measure was an estimate of the percent maximum voluntary contraction (%MVC), based on weight of tools and parts and population strength data, adjusted for extreme posture or speed. Jobs were then predicted to be either hazardous or safe (for all UEMSDs), based on exposure data and judgement. CTS was determined by reviewing OSHA 200 logs and plant medical records. The proportion of CTS in the overall study group during the 20 months of case ascertainment was 17.5 per 100 FTEs. If the occurrence of CTS did not vary over this period, the proportion of CTS in a 12-month period would be 10.5 per 100 FTEs. The hazardous jobs had a RR for CTS of 2.8 (0.2, 36.7) compared to the safe jobs. Potential for survivor effect (79% of the workforce was laid off the year before the study), limited latency period (8-32 months), and the potential for incomplete case ascertainment (under reporting is common on OSHA 200 logs, and logs were not reviewed for the first

12 months of the study) limit confidence in this estimate. One of the more hazardous jobs, the Ham Loaders, required extreme wrist, shoulder and elbow posture and was rated 4 on a 5-point scale for force, yet there was no observed morbidity. Since this job did not start until 1989, the period of observation for musculoskeletal disorders for this job was only 8 months. Other jobs studied allowed for up to a 32-month latency period. The possibility of differential case ascertainment between exposed and unexposed jobs exists, both because of different observation periods, as well as the likelihood that turnover may have been greater in the exposed jobs. It is also unclear whether employees worked full-time or part-time hours.

Nathan et al. [1988] studied median nerve conduction of 471 randomly selected workers from four industries (steel mill, meat/food packaging, electronics, and plastics manufacturing). Jobs were grouped into 5 relative levels of force (from very light to very high) after observation of job tasks. Jobs were also rated for repetitiveness (5 levels). Thirty-nine percent of the study subjects had impaired sensory conduction, or "slowing" of the median nerve. The 5 exposure groups were defined as follows: Group 1 is very low force, low repetition (VLF/LR); Group 2 is low force, very high repetition (LF/VHR); Group 3 is moderate force, moderate repetition (MF/MR); Group 4 is high force/moderate repetition (HF/MR); and Group 5 is very high force/high repetition (VHF/HR). The most logical comparisons to evaluate the effect of force would be Groups 3, 4, and 5 (moderate, high, and very high force) compared to Group 1 (low force). Group 2 jobs are not a good comparison because they are very highly repetitive, which may confound the comparisons. The authors reported a significantly higher number of subjects with median nerve slowing in Group 5 (VHF/HR) compared to Group 1 (VLF/LR), but not in other groups, using an uncommon statistical method (pairwise unplanned simultaneous test procedure [Sokal and Rohlf 1981]). The authors also reported that when individual hands were the basis of calculations rather than subjects, Group 3 had a significantly higher prevalence of median nerve slowing. Calculations of the more familiar PRs and chi-squares [Kleinbaum et al. 1982], using the published data, result in higher prevalences of median nerve slowing in each of Groups 3, 4, and 5, compared to Group 1 (PRs: 1.9, 95% CI 1.3-2.7; 1.7, 95% CI 1.1-2.5; and 2.0, 95% CI 1.1-3.4, respectively). A conservative adjustment (Bonferroni) of the significance level to 0.0125 for multiple comparisons [Kleinbaum et al. 1988] would result in Group 5 no longer being statistically significantly different from Group 1 ($p=0.019$), but Group 4 ($p=0.009$) and Group 3 ($p=0.000$) remain statistically significantly higher than Group 1 in prevalence of median nerve slowing.

In 1992, Nathan et al. reported on a follow-up evaluation in the same study group. 67% of the original study subjects were included. Hands (630), rather than subjects, were the basis of analysis in this study. Novice workers (those employed less than 2 years in 1984) were less likely to return than non-novice workers (56% compared to 69%, $p=.004$). Probable CTS was defined on the basis of symptoms reported during a structured interview and a positive Phalen's or Tinel's test. Maximum latency differences in median nerve sensory conduction were determined as in the 1984 study. The authors state that there was no significant difference in the prevalence of slowing between any of the exposure categories in 1989. However, calculations using common statistical methods show significantly higher prevalences of slowing in Group 4 (PR 1.4, 95% CI 0.9-2.1) compared to Group 1. Group 3's prevalence of slowing was 26% compared to Group 1's 18%, but this difference was not statistically significant (p=0.07). Group 5 had the same prevalence of slowing (18%) as Group 1 in 1989; the prevalence of slowing in Group 5 was 29% in 1984. The drop in prevalence of slowing in Group 5 between 1984 and 1989 might be explained by the higher drop-out rate among cases in Group 5 compared to Group 1 (PR=2.9, 95% CI 1.3-6.6). This was not addressed by the authors.

Osorio et al. [1994] studied 56 supermarket workers. Exposure to repetitive and forceful wrist motions was rated as high, moderate, or low, following observation of job tasks (97% initial concordance with 2 independent observers). The CTS case definition was based on symptoms and nerve conduction studies. CTS-like symptoms occurred more often (OR=8.3, 95% CI 2.6-26.4) among workers in the high exposure group compared to the low exposed group. The odds of meeting the symptom and NCS-based CTS case definition among the high exposure group were 6.7 (95% CI 0.8-52.9), compared to the low exposure group.

Punnett et al. [1985] compared the symptoms and physical findings of CTS in 162 women garment workers and 76 women hospital workers such as nurses, laboratory technicians, and laundry workers. Eighty-six percent of the garment workers were sewing machine operators and finishers (sewing and trimming by hand). The sewing machine operators were described as using highly repetitive, low force wrist and finger motions, whereas finishing work also involved shoulder and elbow motions. The exposed garment workers likely had more repetitive jobs than most of the hospital workers. CTS symptoms occurred more often among the garment workers (OR=2.7, 95% CI 1.2-7.6) compared to the hospital workers. There was a low participation rate (40%) among the hospital workers.

POSTURE AND CTS: DEFINITION OF EXTREME POSTURES FOR CTS

We selected those studies which addressed posture of the hand/wrist area including those addressing pinch grip, ulnar deviation, wrist flexion/extension. Posture is a difficult variable to examine in ergonomic epidemiologic studies. It is hypothesized that extreme or awkward postures increase the required force necessary to complete a task. Positive may increase or decrease forceful effort; its impact on MSDs may not be accurately reflected in measurement of posture alone. Reasons that the variable "extreme posture" has not been measured or analyzed in many epidemiologic studies are: (1) because of the extreme variability of postures used in different jobs as well as the extreme variability of postures between workers performing the same job tasks, (2) because several studies have taken into account the effects of posture when determining other measured variables such as force [Silverstein 1987; Moore and Garg 1994]; and (3) stature often has a major impact on postures assumed by individual workers during job activities.

Studies Meeting the Four Evaluation Criteria

Three studies fulfilled the first round criteria for posture and CTS: Moore and Garg [1994], Silverstein et al. [1987], and Stetson et al.[1993]. (Although Stetson et al. [1993] fulfilled the four evaluation criteria, they analyzed a health outcome based on nerve conduction study results, and did not use the symptom and physical exam based diagnosis of CTS. The details of the overall study designs of these three investigations are mentioned above; the following section will cover the posture variable assessment.

For the exposure assessment of the posture variables in the Silverstein study, three representative workers from each selected job were videotaped using two cameras, performing the jobs for at least three cycles. The authors then extrapolated the posture data to non-observed workers.

Stetson et al. [1993] compared nerve conduction results and evaluated work risk factors of 137 asymptomatic industrial workers, 103 industrial workers with hand/wrist symptoms, and 105 randomly selected control subjects not exposed to highly forceful or repetitive hand exertions. They defined a pinch grip as either a pulp pinch between any combination of digits II-V (fingers) and digit I (thumb) or a lateral inch between the radial side of digit II (index finger) and the volar surface of digit I. Wrist flexion was defined as greater than 30°, while wrist extension was defined as greater than 45°. Ulnar deviation was greater than 18°.

Moore and Garg [1994] used a wrist classification system similar to that used by Stetson, classifying the wrist angle estimated from videotape as neutral, non-neutral or extreme if the flexion/extension angle was 0° to 25°, 25° to 45° and greater than 45° respectively; or if ulnar deviation was less than 10°, 10° to 20°, and greater than 20°, respectively.

Strength of Association: Posture and CTS

Silverstein found no significant association between percentages of cycle time observed in extreme wrist postures or pinch grip and CTS. "CTS jobs" had slightly more ulnar deviation and pinching but these differences were not statistically significant. The authors noted that among all the postural variables recorded, the variability between individuals with similar or identical jobs was probably the greatest for wrist postural variables. This individual variation within jobs was not taken into account in the analysis, creating a potential for misclassification of individuals by using the variable "job category" in the analysis. The effect of exposure misclassification is usually to decrease differences between exposure groups and decrease the magnitude of association.

Stetson [1993] found that "gripping greater than 6 pounds" per hand was a significant risk factor for median distal sensory dysfunction (an indicator of CTS) when the study population was divided into exposed and non-exposed groups. "Gripping greater than 6 pounds" is a variable which combines two work-related variables, posture and forceful exertion. As seen with other studies referenced above, the single work-related variable was not found to be associated with median nerve dysfunction, but the combination of variables was significant. Looking specifically at wrist deviation in Stetson's study, the midpalm to wrist sensory amplitude was smaller in the group

not exposed to wrist deviation (p=0.04) compared to those exposed to wrist deviation (contrary to what was expected). Also no significant differences were found in the mean measurements between nonexposed and exposed groups for use of pinch grip.

Moore and Garg's [1994] classification of jobs did not separate the posture variables from other work factors, and used posture along with other variables to classify jobs into "hazardous" and "safe" categories. The RR of CTS occurring in hazardous jobs was 2.8 but not statistically significant (p=0.44).

Studies Meeting at Least One of the Four Criteria

de Krom et al. [1990] compared certain exposure factors between 28 CTS cases from a community sample and 128 CTS cases from a hospital (a total of 156 CTS cases) to 473 community "non-cases" (n=473). The authors relied on self-reported information about duration of exposure (hours per week) to CTS risk factors (flexed wrist, extended wrist, extended and flexed wrists combined; pinch grasp and typing), with respondents recalling exposure back from the present to 5 years prior from the questionnaire date. Four groups of duration were used in the analyses (0; 1-7; 8-19, 20-40 hours/week). In this study, the selection process of cases was not consistent. Initially, a random population sample was used, then hospital outpatients were used to supplement the number of CTS cases when numbers were found to be insufficient. This may be a problem when estimating the etiologic role of workload, as cases seeking medical care may cause a referral bias. However, the authors stated that they came up with same relationship between flexed and extended wrist using only CTS cases from the population based data. The risk of CTS was found to increase with the reported duration of activities with flexed wrist (RRs from 1.5 to 8.7, with increasing hours) or activities with extended wrist (RR from 1.4 to 5.4 with increasing hours) over the past 5 years. but not for working with a flexed or extended wrist in combination, or working with a pinched grasp. Given the period of recall for self-reported exposure (0-5 years), and no independent observation or attributes of exposure, these results must be interpreted with caution (meaning that within the limitations of the data and conclusions, when considered with other studies that have more stringent methods, the RRs seem consistent and supportive and do not offer alternate conclusions).

Armstrong and Chaffin's [1979] pilot study of female sewing machine operators with symptoms and/or signs for CTS compared to controls found that pinch force exertion (exposure measurements estimated from EMG, film analysis) was significantly associated (OR=2.0). Pinch force was a combination of factors - posture and forceful exertion. The authors reported that CTS-diagnosed subjects used deviated wrist postures more frequently than non-diseased, particularly during forceful exertions. What is unable to be answered due to the study design, was whether the deviated postures were necessitated due to symptoms and signs of CTS, or the deviated postures caused or exacerbated the symptoms and signs.

Tanaka's [1995] analysis of the Occupational Health Supplement of the NHIS population survey depended on self-reported CTS, self-reported exposure factors, and occupation of the respondent for analysis. Self-reported bending and twisting of the hand and wrist (OR=5.2) was found to be the strongest variable associated with "medically-called CTS" among recent workers, followed by race, gender, vibration and age (repetition and force were not included in the logistic models). Limitations of self-reported health outcome and exposure do not allow the conclusions of this study to stand alone; however, when examined with the other studies, it suggests a relationship between posture and CTS.

The two other studies which examined postures and its relationship to CTS did not focus on the hand and wrist. The health outcomes and exposure data were based on self-reports, and either did not report participation rates [English 1995] or had low participation, less than 50% [Liss 1995]. English [1995] found a relationship between self-reported rotation of the shoulder and elevated arm and CTS, an OR of 1.8. Liss [1995] found an OR of 11.4 for self-reported CTS comparing risk factors from dental hygienists compared to dental assistants, with self-reported percent of time trunk in rotated position relative to lower body as one of the factors.

Given these limitations of categorizing posture, three studies [Stetson 1993; Loslever and Ranaivosoa 1993; Armstrong and Chaffin 1979] using different methods to measure posture and estimate force, found that the combination of significant force and posture was significantly related to CTS. Marras and Shoenmarklin [1991] also found posture to be significantly associated with CTS when comparing jobs where grip strength was three times greater than in the low risk jobs. In those studies which used self-reports for categorizing posture, the associations were also positive.

Temporal Relationship

There were no longitudinal studies which examined the relationship between extreme posture and CTS. Two cross-sectional studies that met the evaluation criteria addressed the association between posture and CTS. Silverstein did not find a significant relationship between CTS and extreme posture, but exposure assessment was limited to representative workers; inter-individual variability limited the ability to identify actual relationships between postures and CTS. In the Stetson study, the authors mentioned the limitations of interpretation of their posture results due to misclassification of workers. They extrapolated exposure data to non-observed workers, so individual variability in work methods and differing anthropometry are not accounted for. These limitations all influence outcome, and the conclusions must be interpreted with caution, and considered along with biomechanical and laboratory studies.

Coherence of Evidence

Flexed wrist postures may reduce the area of the carpal tunnel thus potentially increasing the pressure in the tunnel with a concomitant increase in the risk of CTS [Skie et al. 1990; Armstrong et al. 1991]. Marras and Shoenmarklin [1993] found that the variables of wrist flexion, extension angular velocity and wrist flexion extension angular acceleration discriminated between jobs with a high versus a low risk of having an upper extremity reportable injury (an OSHA recordable disorder due to repetitive trauma). The authors suggested that this result was due to high accelerations requiring high forces in tendons. Szabo and Chidgey [1989] showed that repetitive flexion and extension of the wrist created elevated pressures in the carpal tunnel compared to normal subjects, and that these pressures took longer to dissipate than in normal subjects. Observed repetitive passive flexion and extension appeared to "pump up" the carpal tunnel pressure; active motion of the wrist and fingers also had an effect over and above that of the passive motions tested. Laboratory studies demonstrate that carpal canal pressure is increased from less than 5mmHg to more than 30 mmHg during wrist flexion and extension [Gelberman et al. 1981].

Exposure-Response Relationship, CTS and Posture

Few studies address exposure-response relationship between CTS and extreme posture. deKrom et al. [1990] reported an increased risk of CTS with workers reporting increasing weekly hours of exposure to wrist flexion (but not wrist extension or a combination of flexion/extension). Laboratory studies also support a dose-response relationship of increased carpal tunnel pressure due to increasing wrist deviation from neutral [JBJS 1995; Weiss et al. 1995] and pinch form [Rempel, ORS abstract, 1994a].

In conclusion, there is **insufficient evidence** in the current epidemiologic literature to demonstrate that awkward postures alone are associated with CTS.

VIBRATION AND CTS

Definition of Vibration for CTS

We selected studies that addressed manual work involving vibrating power tools and CTS specifically.

Studies Meeting the Four Evaluation Criteria

Three of the 8 studies examining the association between vibration and CTS fulfilled the first round criteria, [Chatterjee 1982; Bovenzi 1991; Silverstein 1987]. Chatterjee et al. performed independent exposure assessment of the vibrating tools, and found the rock drillers to be exposed to vibration between the frequencies of 31.5 and 62 Hertz. Bovenzi's study in 1994 compared stone workers (145 quarry drillers and 425 stone carvers) exposed to hand transmitted vibration to 258 polishers and machine operators who performed manual activity only not exposed to hand transmitted vibration. CTS was assessed by a physician, exposure was assessed through direct observation to vibrating tools and by interview. Vibration was also measured in a sample of tools.

Silverstein et al.[1987] is discussed above. Silverstein [1987] had no quantitative measures of vibration, but observed exposure from videotapes and found all jobs with vibration exposure to be highly repetitive and mostly forceful jobs.

Studies Not Meeting the Evaluation Criteria

Clinical case studies of vibration (not controlled for confounders) by Rothfleisch and Sherman [1978] found an excess of power hand tool users among CTS patients. Lucas [1970] examined workers using vibrating hand tools including stone cutters, tunnelers, coal miners, forest workers and grinders (all with a mean of 14 years exposure to vibration) and found CTS in 21%. He found that the prevalence of CTS in some groups was as high as 33% (neither study had a referent group.)

Cannon found that the self-reported use of vibrating tools, in combination with reported forceful and repetitive hand motions, was associated with a greater incidence of CTS than was repetitive motion alone.

Strength of Association: Vibration and CTS

Chatterjee et al. [1982] found a significant difference between rock drillers with symptoms and signs of CTS and the controls using the following NCS measurements: median motor latency, median sensory latency, median sensory amplitude, and median sensory duration, all at the $p < 0.05$ level. Based on nerve conduction measurements, they also found an OR=10.9 for rock drillers having abnormal NCS amplitudes in the median and ulnar nerves compared to controls. Bovenzi found an OR of 23.1 for CTS based on symptoms and physical exam comparing vibration-exposed forestry operators using chain-saws to maintenance workers performing manual tasks. Bovenzi's study in 1994 found an OR =3.43 for CTS defined by signs and symptoms, controlling for several confounders. In the Silverstein study the crude OR for high force/high repetition jobs with vibration compared to high force/high repetition without vibration was 1.9, but not statistically significant. This suggested that there may have been confounding (the OR was not statistically significant) between high force/high repetition and vibration. Nilsson [1990] found that platers operating tools such as grinders and chipping hammers had a CTS prevalence of 14% compared to 1.7 % among office workers. Nathan found an OR of 4 for slowing of nerve conduction velocity when grinders were compared to administrative and clerical workers. Cannon found an OR of 7.0 for CTS with the use of vibrating hand tools, although there was a strong potential for confounding by hand or wrist posture and forceful exertion.

Temporal Relationship

There were no longitudinal studies which examined the relationship between vibration and CTS.

Consistency in Association

All studies examining vibration and CTS examined found a significantly positive relationship between CTS and vibration exposure. Most studies had ORs greater than 3.0, so that results were less likely to be due to confounding.

Coherence of Evidence and Vibration

The mechanism by which vibration contributes to CTS and tendinitis development is not well understood, probably because vibration exposure is usually accompanied by exposure to forceful and repetitive movements. Muscles exposed to vibration exhibit a tonic vibration reflex that leads to increasing involuntary muscle contraction. Vibration has also been shown to produce short-term tactility impairments which can lead to an increase in the amount of force exerted during manipulative tasks. Vibration can also lead to mechanical abrasion of tendon sheaths. Neurological and circulatory disturbances probably occur independently by unrelated mechanisms. Vibration may directly injure the peripheral nerves, nerve endings, and mechanoreceptors, producing symptoms of numbness, tingling, pain, and loss of sensitivity. It has been found in rats that vibration has caused epineural edema in the sciatic nerve [Lundborg 1987]. Vibration may also have direct effects on the digital arteries. The innermost layer of cells in the blood vessel walls appears especially susceptible to mechanical injury by vibration. If damaged, these vessels may become less sensitive to the actions of certain vasodilators that require an intact endothelium. The NIOSH Criteria Document on exposure to hand-arm vibration [1989] quoted Taylor [1982] as follows: " It is not known whether vibration directly injures the peripheral nerves thereby causing numbness and subsequent sensory loss, or whether the para-anaesthesia of the hands is secondary to the vascular constriction of the blood vessels causing ischemia . . . in the nerve organs."

Exposure-Response Relationship CTS and Vibration

In the studies examined, only dichotomous categorizations were made, so conclusions concerning an exposure-response relationship cannot be drawn. However, we can see significantly contrasting rates of CTS between high and low exposure groups. Weislander found that based on exposure information obtained from telephone interviews, CTS surgery was significantly associated with vibration exposure. Exposure for 1-20 years gave an OR of 2.7, more than 20 years gave an OR of 4.8.

In conclusion, there is **evidence** supporting an association between exposure to vibration and CTS.

Confounding and Carpal Tunnel Syndrome

It is clear that CTS has several non-occupational causes. When examining the relationship of occupational factors to CTS, it is important to take into account the effects of these individual factors; that is, to control for their confounding or modifying effects. Studies that fail to control for the influence of individual factors may either mask or amplify the effects of work-related factors. Most of the epidemiologic studies of CTS that address work factors also take into account potential confounders.

Almost all of the studies reviewed controlled for the effects of age in their analysis [Chiang et al. 1990;1993; Stetson et al. 1993; Silverstein et al. 1987; Weislander et al. 1989; Baron et al. 1991; Tanaka 1985, 1987; McCormack 1990]. Likewise, most studies included gender in their analysis, either by stratifying [Schottland 1991; Chiang et al. 1993], by selection of single gender study groups [Morganstern et al. 1991; Punnett et al. 1985] or by including the variable in the logistic regression model [Silverstein et al. 1987; Stetson et al. 1991; Baron et al. 1991]. Through selection of the study population and exclusion of those with metabolic diseases, most studies were able to eliminate the effects from these conditions. Other studies did control for systemic disease [Chiang et al. 1993; Baron et al. 1991]. Anthropometric factors have also been addressed in several studies [Stetson et al. 1993; Nathan et al. 1997; 1992b; Werner 1997]. As more is learned about confounding, more variables tend to be addressed in more recent studies (smoking, caffeine, alcohol, hobbies). In those older studies which may not have controlled for multiple confounders, it is unlikely that they are highly correlated with exposure, especially those with ORs above 3.0. When examining those studies that have good exposure assessment, widely contrasting levels of exposure, and that control for multiple confounders, the evidence supports a positive association between occupational factors and CTS.

Conclusions

There are over 30 epidemiologic studies which have examined workplace factors and their relationship to CTS. These studies generally compared workers in jobs with higher levels of exposure to workers with lower levels of exposure, following observation or measurement of job characteristics. Using epidemiologic criteria to examine these studies, and taking into account issues of confounding, bias, and strengths and limitations of the studies, we conclude the following:

There is **evidence** for a positive association between highly repetitive work and CTS. Studies that based exposure assessment on quantitative or semiquantitative data tended to show a stronger relationship for CTS and repetition. The higher estimates of RR were found when contrasting highly repetitive jobs to low repetitive jobs, and when repetition is in combination with high levels of forceful exertion. There is **evidence** for a positive association between force and CTS based on currently available epidemiologic data. There is **insufficient evidence** for a positive association between posture and CTS. There is **evidence** for a positive association between jobs with exposure to vibration and CTS. There is **strong evidence** for a relationship between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and CTS. Ten studies allowed a comparison of the effect of individual vesus combined work risk factors [Chiang et al. 1990, 1993; Moore et al. 1994; Nathan et al. 1988, 1992; Silverstein et al. 1987; Schottland et al. 1991; McCormack et al.1990; Stetson et al. 1993]. Nine of these studies demonstrated higher estimates of RR when exposure was to a combination of risk factors, compared to the effect of individual risk factors. Based on the epidemiologic studies reviewed above, especially those with quantitative evaluation of the risk factors, the evidence is clear that exposure to a combination the job factors studied (repetition, force, posture, etc.) increases risk for CTS. This is consistent with the evidence that is found in the biomechanical, physiologic, and psychosocial literature.

Table 5a-1. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with repetition

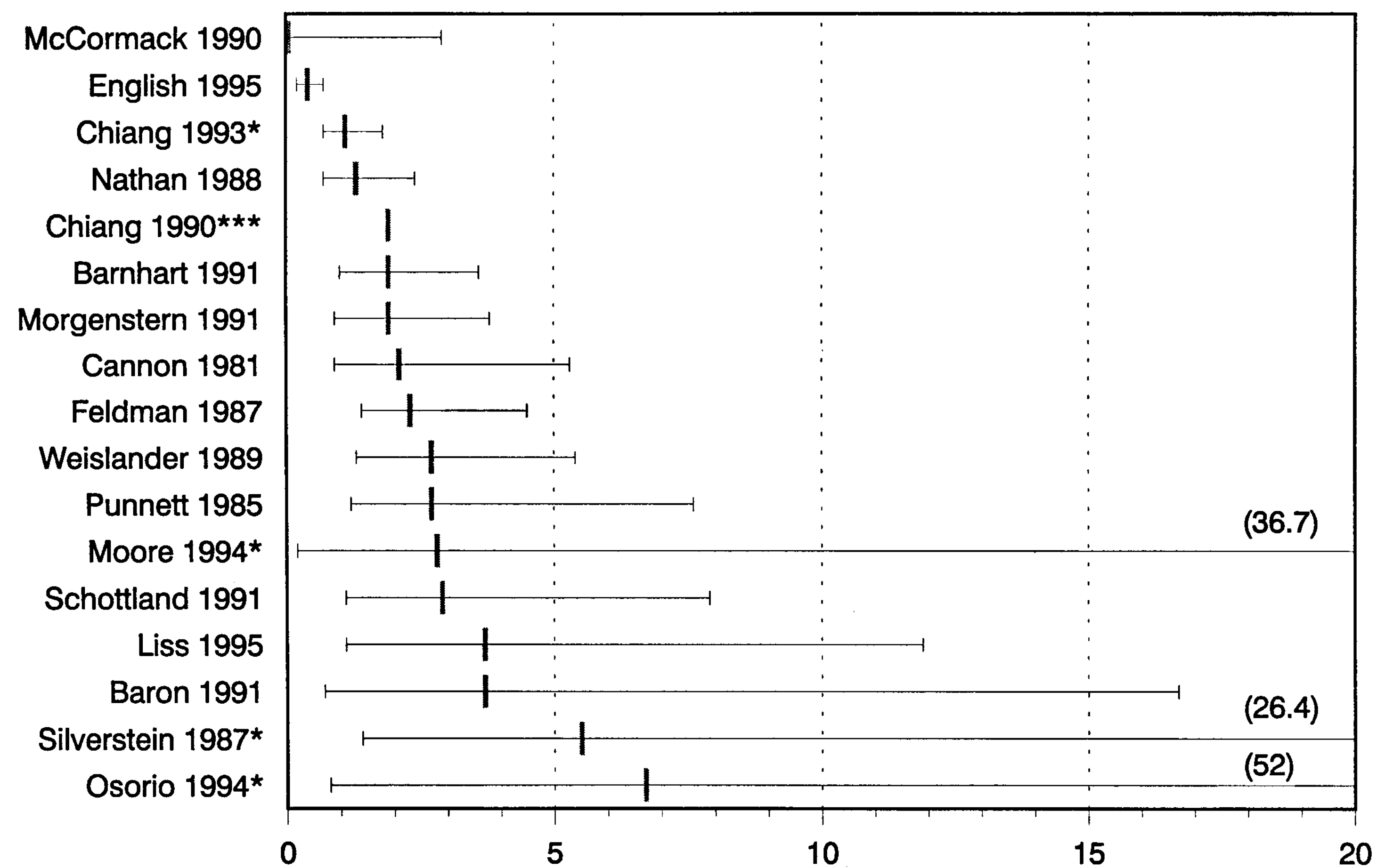
Study (first author and year)	Risk indicator (OR, PRR, IR or *p*-value)*,†	Participation rate ≥70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to repetition
Met all four criteria:					
Chiang 1990	1.87†	Yes	Yes	Yes	Observation or measurements
Chiang 1993	1.1	Yes	Yes	Yes	Observation or measurements
Moore 1994	2.8	Yes	Yes	Yes	Observation or measurements
Osorio 1994	4.8	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	5.5†	Yes	Yes	Yes	Observation or measurements
Met at least one criteria:					
Barnhart 1991	1.9†–4.0	No	Yes	Yes	Observation or measurements
Baron 1991	3.7	No	Yes	Yes	Observation or measurements
Cannon 1981	2.1	NR‡	No	NR	Job titles or self-reports
English 1995	0.4	Yes	Yes	Yes	Job titles or self-reports
Feldman 1987	NR, 2.26†	Yes	No	NR	Observation or measurements
McCormack 1990	0.5	Yes	Yes	NR	Job titles or self-reports
Morgenstern 1991	1.88	Yes	No	No	Job titles or self-reports
Nathan 1988	1.27	NR	Yes	NR	Observation or measurements
Nathan 1992	No association	No	Yes	NR	Observation or measurements
Osorio 1994	8.3†	Yes	Yes	Yes	Job titles or self-reports
Punnett 1985	2.7†	No	Yes	NR	Job titles or self-reports
Schottland 1991	2.86	NR	No	NR	Job titles or self-reports
Stetson 1993	NR	Yes	Yes	NR	Observation or measurements
Weislander 1989	2.7†	Yes	Yes	No	Job titles or self-reports
Met none of the criteria:					
Liss 1995	5.2 3.7†	No	No	No	Job titles or self-reports

*Some risk indicators are based on a combination of risk factors—not on repetition alone (i.e., repetition plus force, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

‡Not reported.

Figure 5a-1. Risk Indicator for "Repetition" and Carpal Tunnel Syndrome
(Odds Ratios and Confidence Intervals)



*Studies which met all four criteria
**Significant risk factor reported without confidence limits
Note: Some studies indicate statistical significance without a risk indicator. See Table 5a-1.

Table 5a-2. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with force

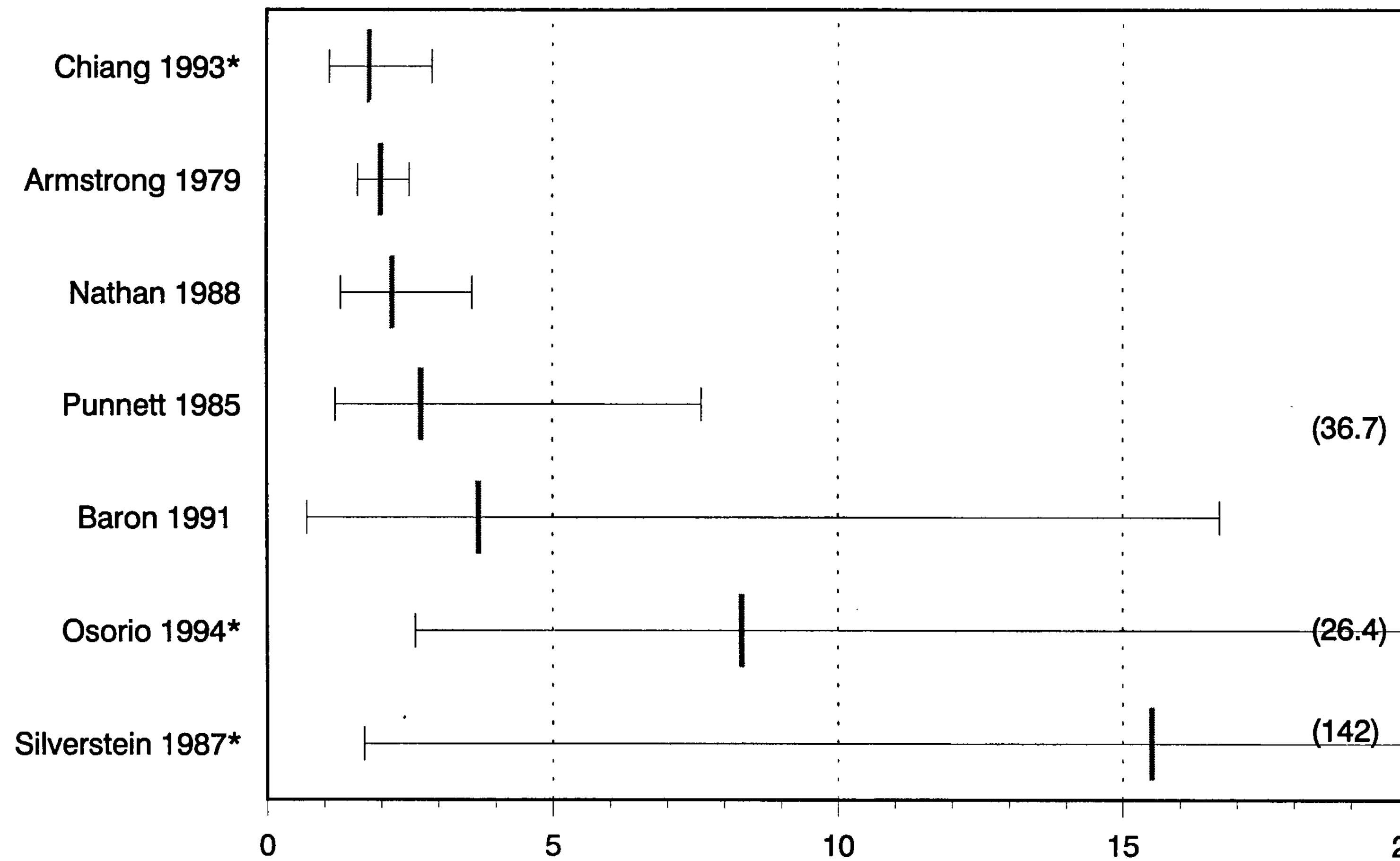
Study (first author and year)	Risk indicator (OR, PRR, IR, or p-value)*,†	Participation rate ≥70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to force
Met all four criteria:					
Chiang 1993	1.8†	Yes	Yes	Yes	Observation or measurements
Moore 1994	NR†	Yes	Yes	Yes	Observation or measurements
Osorio 1994	8.3†	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	15.5†	Yes	Yes	Yes	Observation or measurements
Stetson 1993	NR‡	Yes	Yes	Yes	Observation or measurements
Met at least one criteria:					
Armstrong 1979	2.0†	NR	No	No	Observation or measurements
Baron 1991	3.7	No	Yes	Yes	Observation or measurements
Nathan 1988	2.2†	NR	Yes	NR	Observation or measurements
Punnett 1985	2.7†	No	Yes	NR	Job titles or self-reports

*Some risk indicators are based on a combination of risk factors—not on force alone (i.e., force plus repetition, posture, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

‡Not reported.

Figure 5a-2. Risk Indicator for "Force" and Carpal Tunnel Syndrome
(Odds Ratios and Confidence Intervals)



*Studies which met all four criteria
Note: Some studies indicate statistical significance without a risk indicator or reported a statistical significant association without a risk indicator. See Table 5a-2.

Table 5a-3. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with posture

Study (first author and year)	Risk indicator (OR, PRR, IR, or *p*-value)*,†	Participaton rate ≥70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to posture
Met at least one criteria:					
DeKrom 1990	5.4–8.7†	Yes	Yes	NR‡	Job titles or self-reports
English 1995	1.8†	Yes	Yes	Yes	Job titles or self-reports
Silverstein 1987	NR	Yes	Yes	No	Observation or measurements
Met none of the criteria:					
Liss 1995	3.7†	No	No	No	Job titles or self-reports

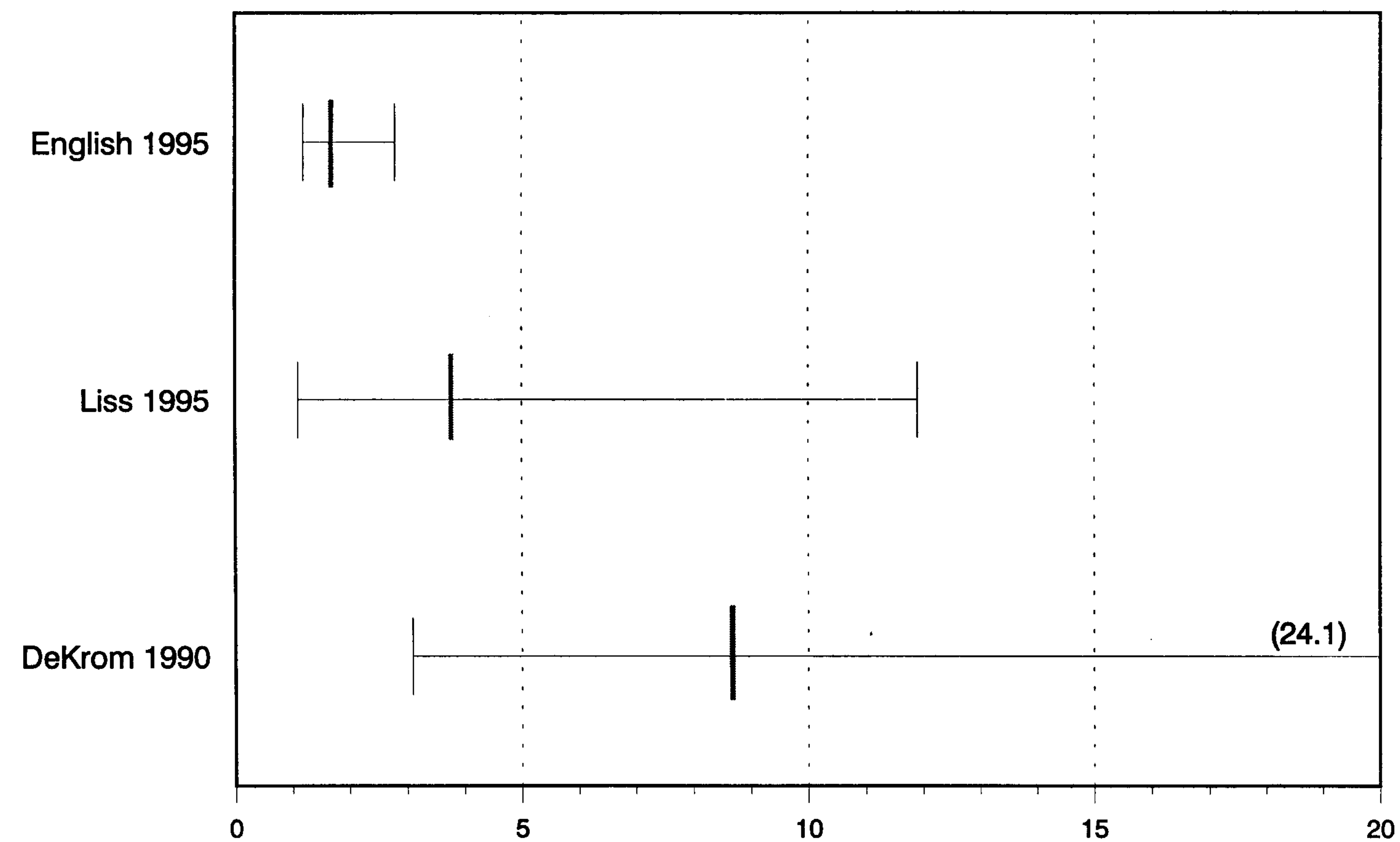
*Some risk indicators are based on a combination of risk factors—not on posture alone (i.e., posture plus repetition, force, or vibration). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance.

‡Not reported.

Figure 5a-3. Risk Indicator for "Posture" and Carpal Tunnel Syndrome

(Odds Ratios and Confidence Intervals)



Note: Some studies indicate statistical significance without a risk indicator. See Table 5a-3.

Table 5a-4. Epidemiologic criteria used to examine studies of carpal tunnel syndrome (CTS) associated with vibration

Study (first author and year)	Risk indicator (OR, PRR, IR, or p-value)*,†	Participation rate ≥70%	Physical examination, and/or nerve conduction studies	Investigator blinded to case and/or exposure status	Basis for assessing hand exposure to vibration
Met all four criteria:					
Chatterjee 1992	10.89†	Yes	Yes	Yes	Observation or measurements
Silverstein 1987	5.3†	Yes	Yes	Yes	Observation or measurements
Met at least one criteria:					
Bovenzi 1991	23.1†	NR‡	Yes	Yes	Observation or measurements
Bovenzi 1994	3.4†	Yes	Yes	No	Observation or measurements
Cannon 1981	7.0†	Yes	No	NR	Job titles or self-reports
Farkkila 1988	NR†	NR	Yes	NR	Observation or measurements
Koskimies 1990	NR†	NR	Yes	NR	Observation or measurements
Tanaka 1997	1.8†	Yes	No	No	Job titles or self-reports
Weislander 1989	3.3†	Yes	Yes	No	Job titles or self-reports

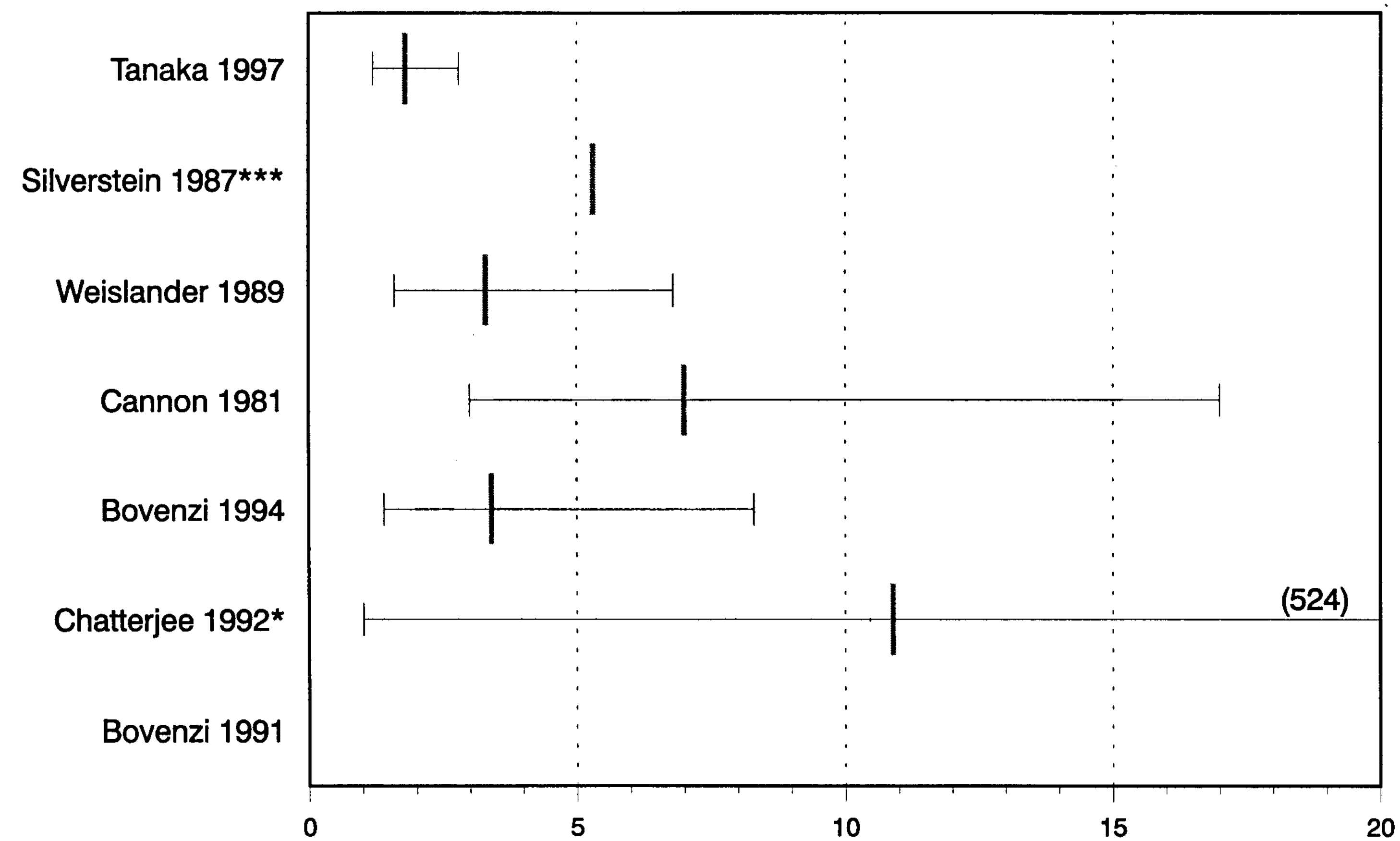
*Some risk indicators are based on a combination of risk factors—not on vibration alone (i.e., vibration plus repetition, posture, or force). Odds ratio (OR), prevalence rate ratio (PRR), or incidence ratio (IR).

†Indicates statistical significance. If combined with NR, a significant association was reported without a numerical value.

‡Not reported.

Figure 5a-4. Risk Indicator for "Vibration" and Carpal Tunnel Syndrome

(Odds Ratios and Confidence Intervals)



Note: Some studies indicate statistical significance without a risk indicator. See Table 5a-4.

**Significant risk factor reported without confidence limits

*Studies which meet all four criteria

Table 5a–5. Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Armstrong and Chaffin 1979	Case-control	18 female sewing machine operators with CTS histories compared to 18 female sewing machine operators without CTS histories.	Outcome: CTS defined as history of symptoms, surgical decompression of the median nerve, positive Phalen's test, or thenar atrophy. Exposure: Hand/wrist postures and estimation of forearm flexor force in various wrist and hand postures assessed by film analysis and EMG.	—	—	For pinch force exertion: 2.0 For hand force: 1.05	1.6-2.5 1.0-1.2	Participation rate: Not reported. All cases of CTS diagnosed prior to study in working sewing machine operators, may cause referral bias in estimating role of workload. Subjects excluded if history of fractures, metabolic or soft tissue disease. No association found between hand size or shape and CTS. CTS diagnosed subjects used deviated wrist more frequently than non-diseased, particularly during forceful exertions.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Barnhart et al. 1991	Cross-sectional	Ski manufacturing workers: 106 with repetitive jobs compared to 67 with non-repetitive jobs.	Outcome: CTS determined by: (1) Case 1: Electro-diagnosis of median-ulnar difference (latency on response time); (2) Case 2: Either Tinel's or Phalen's test and electro-diagnosis; (3) Case 3: Ever having symptoms of hand pain, tingling, numbness, or nocturnal hand pain and Tinel's or Phalen's test and electro-diagnosis. Exposure: Jobs classified as repetitive and non-repetitive. Repetitive jobs entailed repeated or sustained flexion, extension, or ulnar deviation of the wrist by 45°, radial deviation by 30°, or pinch grip (determined by observation).	Case 1: 34% Case 2: 15.4% Case 3: 32.5%	19% 3.1% 18.2%	1.9 3.95 1.6	1.0-3.6 1.0-15.8 0.8-3.2	Participation rate: 70% (repetitive jobs), 64% (non-repetitive jobs). Examiner blinded to subject's job status but clothing may have biased observations. Controlled for age and gender. Found for both right and left hand of those with repetitive jobs; mean difference between distal sensory latencies of median and ulnar nerves were primarily due to a shorter mean sensory latency of the ulnar nerve. There was no difference in median nerve distal sensory latencies between groups. Hormonal status, systemic disease included in questionnaire. Diabetes significantly more frequent in those with CTS than without ($p=0.01$).

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Baron et al. 1991	Cross-sectional	119 female grocery checkers vs. 56 other female grocery store employees (comparison group).	Outcome: CTS case defined as having moderate to severe symptoms of pain, stiffness, numbness, tingling. Symptoms begun after employment in the current job; lasted > one week or occurred > once a month during the past year; no history of acute injury to part of body in question and a positive physical exam of either Phalen's or Tinel's test. Exposure: Based on job category, estimates of repetitive, average, and peak forces based on observed and videotaped postures, weight of scanned items, and subjective assessment of exertion. Exposure level in checkers: Average forces: Low Peak force: Medium Repetition: Medium Exposure level in referents: Average force: Medium Peak force: Medium to low Repetition: Medium.	11%	4%	3.7	0.7-16.7	Participation rate: 85% checkers; 55% non-checkers in field study. Following telephone survey 91% checkers and 85% non-checkers. Adjusted for duration of work. Total repetitions/hr ranged from 1,432 to 1,782 for right hand and 882 to 1,260 for left hand. Multiple awkward postures of all upper extremities recorded but not analyzed in models. Examiners blinded to worker's job and health status. Controlled for duration of work, hobbies.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Bovenzi et al. 1991	Cross-sectional	65 vibration-exposed forestry operators using chain-saws compared to referents composed of 31 maintenance workers (electricians, mechanics, and painters).	Outcome: CTS cases defined as having symptoms of pain, numbness, or tingling in the median nerve distribution, and physical exam findings of Tinel's or Phalen's test, diminished sensitivity to touch or pain in 3½ fingers on radial side, weakness in pinching or gripping. Exposure: Direct observation of awkward postures, manual forces, and repetitiveness evaluated via checklist. The focus of the study was to compare vibration-exposed workers to controls doing manual work. Vibration measured from two chain-saws. Vibration exposure for each worker assessed in terms of 4-hr energy-equivalent frequency-weighted acceleration according to ISO 5,349.	38.4%	3.2%	21.3 (adjusted)	—	Participation rate: Not reported. Examiners blinded to case status. Controlled for age and ponderal index (height and weight variable). Metabolic disease also considered. Controls also found to have several risk factors for MSDs at work—static arm and hand overload, overhead work, stressful postures, non-vibrating hand-tool use. Controls had a greater proportion of time in work cycles shorter than 30 sec than forestry workers. Chain saw operators worked outdoors and were exposed to lower temperatures than maintenance workers.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Bovenzi et al. 1994	Cross-sectional	Case group: Stone workers employed in 9 districts in Northern and Central Italy; 145 quarry drillers and 425 stone carvers exposed to vibration. Referent group: Polishers and machine operators (n=258) who performed manual activity but were not exposed to hand-transmitted vibration. All stone workers employed in 6 districts participated in the survey (n=578, 69.8%), whereas, in the three other districts they were selected on basis of random sampling of the quarries and mills in the geographic areas (n=250, 30.2%).	Outcome: CTS assessed by physician assessment. CTS defined as symptoms, (1) Parathesias, numbness, or pain in median nerve distribution; (2) Nocturnal exacerbation of symptoms and positive Tinel's or Phalen's test. Exposure: Direct observation of vibrating tools assessed by interview. Vibration measured in a sample of tools.	8.8%	2.3%	3.4	1.4-8.3	Participation rate: 100%. "All the active stone workers participated in the study, so self-selection was not a source of bias." Physician administered questionnaires containing work history and examinations, so unlikely to be blinded to case status. Adjusted for age, smoking, alcohol consumption, and upper limb injuries. Leisure activities and systemic diseases included in questionnaire. Univariate analysis showed no association between systemic diseases and vibration so were not criteria for exclusion. Dose-response for CTS and lifetime vibration exposure not significant.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Cannon et al. 1981	Case-control	Aircraft engine workers at 4 plants: 30 CTS cases identified through worker's compensation claims and medical department records during a 2-year period compared to 90 controls from the same plant, 16 workers receiving compensation benefits for treatment of CTS, and 14 cases who had not received compensation benefits. Three controls randomly chosen from the same plant for each CTS case.	Outcome: CTS cases identified through worker's compensation claims and medical department records during a 2-year period. Exposure: Based on job category, years on the job, identified through record review and interviews. Exposure to vibrating tools, repetitive motion. Buffing, grinding, and hand tools were measured with an accelerometer and found to be in the range of 10 to 60 Hz.	—	—	For vibrating hand tool use: 7.0 For repetitive motion tasks: 2.1 History of gynecologic surgery: 3.7 Years on the job: 0.9	3.0-17 0.9-5.3 1.7-8.1 0.8-1.0	Participation rate: Participation rate unable to be calculated from data presented. 30 cases identified through record review of 20,000 workers. Cases and controls on gender. Controlled for gynecologic surgery, race, diabetic history, years on the job, use of low-frequency vibrating tools. Information obtained through self-administered questionnaires and personal interviews on cases and controls on age, sex, race, weight, occupation, years employed, worker compensation status, history of metabolic disease, hormonal status of females, history of gynecologic surgery. Number of years employed significantly different among cases (5.5 years) and controls (11.7 years). Range of years employed among cases included 0.1 year to 28 years.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

				MSD prevalence				
Study	Study design	Study population	Outcome and exposure	Exposed workers	Referent group	RR, OR, or PRR	95% CI	Comments
Chatterjee et al. 1982	Case-control	16 rock drillers compared with 15 controls.	Outcome: CTS was determined by symptoms from questionnaire and interview by medical investigator, clinical exams carried out blindly, and nerve conduction studies. For Table 5-7, CTS based solely on NCS results; Table 5-9 based on symptoms and NCS. Exposure: To vibration carried out by measurement of vibration spectra of the rock drills and observation of jobs. Exposed group were those miners who regularly used rock-drills in the fluorspar mines or other miners using similar rock-drills. Exposure varied from 18 months to 25 years (mean 10 years). The rock drillers were exposed to vibration level in excess of the damage level criterion between the frequencies of 31.5 and 62 Hz.	44%	7%	Abnormal amplitudes of digital-action potentials from fingers supplied by the median and ulnar nerves; the OR in vibration exposed vs. controls: OR=10.89	1.02-524	Participation rate: 93%. Examiners blinded to case status. Groups standardized for age and gender. Exclusionary criteria: History of constitutional white finger, secondary causes of Raynaud's phenomenon, > one laceration or fracture in the hands or digits, severe or complicated injury involving nerve or blood vessels or significant surgical operation, history of exposure to vibration from tools other than rock drills. Significant differences found between controls and vibration group for symptoms of numbness and tingling: median motor latency; median sensory latency; median sensory amplitude; median sensory duration. All at the $p < 0.05$ level. Skin temperature controlled for in NCVs.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Chiang et al. 1990	Cross-sectional	207 active workers from 2 frozen food plants divided into 3 groups: (1) Low-cold, low-repetition (comparison group, mainly office staff and technicians, n=49), (2) Low-cold, high-repetition (non-frozen food packers, n=37), (3) High-cold, high-repetition (frozen food packers, n=121).	Outcome: CTS defined as symptoms of numbness, pain, tingling in the fingers innervated by the median nerve, onset since work in current job, no relationship to systemic disease or injury and physical exam of Tinel's test or Phalen's sign. Nerve conduction testing was performed on motor and sensory nerves of both upper limbs. If subject had abnormal results and symptoms and physical exam findings, was considered CTS. If no symptoms, considered as subclinical CTS. Exposure: Job analyses conducted by industrial hygienist, to cold and repetition assessed by observation. Highly repetitive jobs had cycle times <30 sec. >50% of cycle time cold exposure was defined as whether the job required hands to be locally exposed to cold. The mean skin temperature of their hands was in the range of 26 to 28°C, even with wearing gloves.	Group 2: 40.5% clinical plus 8.1% sub-clinical Group 3: 37.2% clinical plus 22.3% sub-clinical	Group 1: 4% clinical plus 2% sub-clinical	Group 2 vs. Group 1: OR=8.28 Group 3 vs. Group 1: OR=11.66 Logistic Regression Model: Cold: OR=1.85 ($p<0.22$) Repetitiveness: OR=1.87 ($p<0.018$) Cold x Repetitiveness: OR=1.77 ($p<0.03$)	1.18-58.3 2.92-46.6	Participation rate: Not specifically mentioned, however, paper states that "in order to prevent selective bias, all of the employees in the factories were observed initially." Examiners blinded to exposure status and medical history. Controlled for age, sex, and length of employment. Interaction terms tested. Excluded subjects with diabetes, thyroid function disorders, history of forearm fracture, unspecified polyneuropathy, rheumatoid arthritis. Workers in cold groups wore gloves and exerted higher forces than workers in non-cold groups. Force was not evaluated in this study. Confounding is possible according to authors. CTS was independent of age and length of employment. Authors considered this to be due to healthy worker effect. OR for group 1 vs. group 2 is 8.3 (1.2-58.3) when adjusted for sex but 2.2 (0.2-21.1) when adjusted for sex, age, and length of employment suggesting survival bias.

(Continued)

Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Chiang et al. 1993	Cross-sectional	207 fish processing workers divided in 3 groups: (1) low-force, low-repetition (comparison group, n=61); (2) high-force or high-repetition (n=118); (3) high-force and high-repetition (n=28).	Outcome: CTS defined as having symptoms of numbness, pain, or tingling in the fingers innervated by the median nerve, onset after job began, and no evidence of systemic disease or injury and physical exam findings of positive Tinel's sign or Phalen's test. Exposure: Assessed by observation and recording of tasks and biomechanical movements of 3 workers, each representing 1 of 3 study groups. Highly repetitive jobs with cycle time <30 sec or >50% of cycle time performing the same fundamental cycles. Hand force from EMG recordings of forearm flexor muscles. Classification of workers into 3 groups according to the ergonomic risks of the shoulders and upper limbs: Group 1: low-repetition and low-force; Group 2: high-repetition and high-force; Group 3: high-repetition or high-force.	Group 2 (Male): 6.9% Group 2 (Female): 18.0% Group 3 (Male): 0.0% Group 3 (Female): 36.4%	Group 1 (Male): 3.1% Group 1 (Female): 13.8%	2 vs. 1 (male): OR= 2.2 2 vs. 1 (female): OR=1.3 3 vs. 1 (male): — 3 vs. 1 (female): OR=2.6 Repetition: OR=1.1 Force: OR=1.8 Repetition and force: OR=1.1 Male vs. female: OR=2.6	0.2-22.0 0.5-3.5 — 1.0-7.3 0.7-1.8 1.1-2.9 0.7-1.8 1.3-5.2	Participation rate: Paper stated that all of the workers who entered the fish-processing industry before June 1990 and were employed there full-time were part of the cohort. Workers examined in random sequence to prevent observer bias; examiners blinded to case status. Analysis controlled for age, stratified by gender. Contraceptive use (females): significant (OR=2.0, 95% CI 1.2 to 5.4); tubal ligation not significant. Workers with hypertension, diabetes, history of traumatic injuries to upper limbs, arthritis, collagen diseases excluded from study group. No significant age difference in exposure groups. Physician-observed cases about ½ the prevalence of symptoms of elbow pain (9.8 vs. 18.0; 15.3 vs. 19.5; 35.7 vs. 17.9). Dose-response for symptoms both in the hand and in the wrist ($p<0.03$) and physician-observed CTS ($p<0.015$). Age, gender, repetitiveness, forceful movement of upper limbs and interaction of repetitiveness and forceful movement calculated in logistic regression. Significant trend for duration of employment in <12 months but not 12 to 60 months or >60 months.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
DeKrom et al. 1990	Nested case control	28 CTS cases from a community sample and 128 CTS cases from a hospital (total n=156) compared to community non-cases (n=473). Participants blinded to aim of study—told it was about "general health."	Outcome: Tingling pain and numbness in median distribution, frequency ≥2/week, awakened at night and nerve conduction studies. Motor latency < 4.5 months, different median to ulnar DSL < 4.0 months, controlled for temperature. CTS diagnosed by clinical history and neurophysiological tests. Exposure: Awkward hand/finger postures and pinch grasps assessed by questionnaire: Self-reported information about duration of exposure (hr/wk) to flexed wrist, extended wrist, extended and flexed wrist combined, pinched grasp. Typing hr categorized as 0, 1 to 7, 8 to 19, 20 to 40 hr/wk of exposure 0 to 5 years ago, responses truncated at 40 hr/wk.	5.6% prevalence in the general population (28 cases from 501 subject community sample)	—	For work: 20 to 40 hr/wk with flexed wrist: OR=8.7 For work: 20 to 40 hr/wk with extended wrist: OR= 5.4	3.1-24.1 1.1-27.4	Participation rate: 70% response rate obtained for both hospital and community samples. Controlled for age, weight, slimming courses, gender, and checked for interactions. Cases seeking medical care may cause referral bias in estimating etiologic role of work-load. However, authors came up with same relationship between flexed and extended wrist using only CTS cases from population-based data. The associations from this study are based on very small sample sizes. >64% of cases reported 0 hr/wk to each of the exposures. In random sample, age, and sex stratified, included twice as many females as males. No significant relationship between pinch grasp or typing. Dose-response found for duration of activities with flexed or extended wrist statistically significant; dose-response relationship for both present but not statistically significant. Typing hr not significant but very small numbers (<5 in comparison groups); may have been unable to detect a difference. Females with hysterectomy without oophorectomy significantly increased risk, PRR=2.0 (1 to 3.6), compared to females not operated on; increase may be detection bias. Wrist fractures, thyroid disease, rheumatism, and diabetes not significant for CTS. Varicosis significant risk for males 12.0 (3.6-40.1). Oral contraceptives not significantly associated with CTS.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
English et al. 1995	Case-control	Cases: CTS patients (N=171) ages 16 to 65 years from orthopedic clinics. Controls: (n=996) 558 males and 438 females attending the same clinics diagnosed with conditions other than diseases of the upper limb, cervical, or thoracic spine; ages 16 to 65 years.	Outcome: CTS based on agreed criteria diagnosed by orthopedic surgeons using common diagnostic criteria (not specified). Exposure: Based on self-reported risk factors at work: questions addressed: awkward postures, grip types, wrist motions, lifting, shoulder postures, static postures, etc. and job category.	—	—	Rotating shoulder with elevated arm and CTS: OR=1.8 Repeated finger tapping and CTS: OR=0.4	1.2-2.8 0.2-0.7	Participation rate: 96%. Due to design of study (cases selected by diagnoses), blinding of examiners not an issue. Adjusted for height, weight, and gender. Significant negative association with height and presentation at the clinic as a result of an accident and CTS. A significantly positive association with height. Included "frequency of movements" in regression analysis.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence				Comments
				Exposed workers	Referent group	RR, OR, or PRR	95% CI	
Farkkila et al. 1988	Cross-sectional	79 chain saw users randomly selected from 186 forestry workers with >500 hr of sawing/year.	Outcome: CTS based on nerve conduction studies, motor and sensory conduction velocity, distal and proximal latencies, Tinel's and Phalen's tests and subjective symptoms. Exposure: Chain saw vibration not measured. Duration of chain saw use determined by interview.	26%	—	Significant correlation between numbness in the hands ($r=0.38$, $p<0.05$) and CTS and muscle fatigue ($r=0.47$, $p<0.05$) and CTS.	—	Participation rate: 100% of professional forestry workers. Significant correlation between CTS and HAVs found. Randomly selected from EMG out of 186. Alcohol consumption did not correlate with numbness in the hands or arms ($r=0.14$, $p=NS$) or sensory disturbances. Only motor nerve recordings were analyzed for this study.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Feldman et al. 1987	Cross-sectional for symptom survey Prospective for nerve conduction studies	586 electronics workers at a manufacturing firm with 700 employees.	Outcome: Based on questionnaire survey and abbreviated neurologic examination that involved tests of hand sensation, finger grip, and strength of thenar muscles. Tinel's and Phalen's done. "Standard nerve conduction" of left and right median nerves. Exposure: Two subjects randomly selected for biomechanical analyses from each of four high-risk areas, determined from questionnaire and walk-through observations of tasks involving repetitive flexion, extension, pinching, and deviated wrist postures. Videotaping and electromyography done. Highly repetitive job task defined as <30 sec cycle or >50% of cycle performing the fundamental cycle. Wrist posture characterized in terms of flexion and extension: >45 flexed, 15 to 45 flexion, neutral, 15 to 45 extension, and >45 extension and deviation. Hand posture characterized by 6 types of grip. No quantitative measures of vibration were obtained.	Wrist tingling and numbness: 18%	Wrist tingling and numbness: 8.7%	— Numbness and tingling in fingers: OR=2.26 High-risk vs. low-risk jobs: $p<0.005$	— 1.4-4.46	Participation rate: 84%. Examiners blinded to case and exposure status: Not stated. Analysis not controlled for confounders. Questionnaire obtained data on past medical history, exposure to neurotoxins, cigarettes, hobbies, and symptoms. For nerve conduction testing, the temperature of limbs was monitored and controlled for. More females were in high-risk areas and jobs than males. There were no workers >60 years old in high-risk group. There were 34 workers >60 years in comparison groups. Rheumatoid arthritis more prominent in low-risk group (8.2%) than high-risk (2.4%) group. Nerve conduction in high-risk workers performed year 1 and year 2. Right sensory amplitude abnormal (<8μV) in 22% of workers at year 1 and 35.5% at year 2. Left sensory amplitude abnormal in 16.7% and 29% at year 2. Most apparent changes (increases) seen in bilateral sensory velocities and motor latencies (abnormal >4.5). Right motor latency abnormal in 8% at year 1 and 11% in year 2. Left motor latency abnormal in 2% in year 1 and 23% at year 2. Authors offered parameters for staging CTS in high-risk subjects (0 to 4 stages).

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Franklin et al. 1991	Retro-spective cohort: from 1984 to 1988	Workers in Washington State (n=1.3 million full-time workers in 1988). Worker's compensation data for Washington State, using compensable (time loss) and non-compensable claims for January 1984 to December 1988.	Outcome: Assessed using workers' compensation claims for CTS using ICD codes 354.0 and 354.1. Incident claim was the first appearance of a paid bill for claimant with a physician diagnosis. Algorithm was developed to identify unique claimants which removed multiple claims. Exposure: Not measured. Workers in the same industrial classification assumed to share similar workplace exposures.	25.7 claims/ 1,000 FTEs (oyster and crab packers) 23.9 claims/ 1,000 FTEs (meat and poultry workers)	1.74 claims/ 1,000 FTEs (industry wide rate)	14.8 (oyster and crab packers) 13.8 (meat and poultry workers)	11.2-19.5 11.6-16.4	Participation rate: This is a records review so it does not apply. Among claimants, the female-to-male ratio was 1.2:1. Mean age of claimants was 37.4. Diagnosis and data entry errors comprised 25% of CTS surgery claims – cases were not coded as CTS. 82% of claims were true cases of CTS.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Koskimies et al. 1990	Cross-sectional	217 forestry workers who used chain saw >500 hr during previous 3 years.	Outcome: 125 randomly selected for EMG of sensory and motor nerves both hands. CTS diagnosis based on symptoms, exclusion of other conditions, results of Phalen's and Tinel's test, and findings in sensory and motor nerve EMG. Exposure: Number of years of vibration exposure (only workers who had 500 hr during previous 3 years were included.	Active vibration: 5% white finger CTS: 20%		Alcohol consumption and CTS cases $r=0.15$ Vibration exposure time and motor NCV in median nerve of right hand: $r=-0.27$ but not left hand: $r=-0.12$ Exposure time with both motor NCV in ulnar nerve of right hand $r=-0.26$ and left hand $r=-0.39$. Distal latencies in median nerve and exposure in right hand $r=0.17$; left hand $r=0.21$. Numbness and sensory NCS of median nerve; right hand $r=0.679$; left hand $r=0.53$.	$p=\text{NS}$ $p=0.01$ $p=\text{NS}$ $p=0.05$ $p<0.001$ $p=0.05$ $p=0.05$ $p<0.001$ $p<0.01$	Participation rate: Not reported. Examiners were not blinded to exposure status because of design of study. No comparison group because study was part of longitudinal study of workers followed since 1972. Most of 25 CTS workers had mild symptoms at work despite severe reduction of sensory NCS of median nerve. Males with primary Raynaud's disease, rheumatoid arthritis, diabetes, or positive urine glucose slide test results excluded from study. 12 (48%) of those with CTS had bilateral diagnosis. The authors stated that the left hand is the dominant working hand in sawing, the right hand acting more to direct the saw during the operation.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Liss et al. 1995	Cross-sectional	1,066 of 2,142 dental hygienists from Ontario Canada Dental Hygienists Association compared to referent group, 154 of 305 dental assistants.	Outcome: Mailed survey, 2 CTS case definitions: (1) Based on positive response to "told by a physician that you had CTS" (2) If during last 12 months, for >7 days experienced numbness and tingling, pain, or burning in distribution of median nerve, night pain or numbness in hands, and no previous wrist/hand injury. Exposure: Based on mailed survey: Length of practice, days/wk worked, patients/day, patients with heavy calculus, percent of time trunk in rotated position relative to lower body, instruments used, hr of typing/wk, type of practice.	Responder told that they had CTS: 7% Question-naire based CTS: 11%		Responder told that they had CTS: 0.9% OR = 5.2 Questionnaire based CTS: 3.0% OR = 3.7	0.9-32 1.1-11.9	Participation rate: 50% response rate from both groups. Study population >99% female. OR were age adjusted. Confounders considered included typing, hobbies, and taking estrogens.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Loslever and Ranaivosoa 1993	Cross-sectional	17 selected jobs with frequent and repeated absences of workers due to CTS investigated at the request of occupational doctors and managers. Biomechanical data recorded on a number of workers from each job, ranging from 1 to 4 workers. Involving 961 workers.	Outcome: Occupational physician from each factory involved in the study completed questionnaire concerning each job and the number of CTS cases. The prevalence of CTS was then calculated from ratio of CTS cases and total number of employees that worked at that place. Exposure: Videotaping of movements, use of vibrating tools, and two measurement techniques used: (1) Flexion-extension measurements: Subjects recorded at several points during the day for 15 min. An angle meter used to measure flexion-extension angles of the wrist: Rated high flexion, low flexion, low extension, and high extension using fuzzy cutting functions. Each modality characterized by its arithmetic mean and its relative duration. (2) Force: Electromyography used; values under 2 daN considered as low forces. Calculated time spent over 2 daN, maximal force, number of peak exertions, and the arithmetic mean of the n values during a period.	Mean prevalence rate among jobs (jobs chosen at workplaces where CTS had been reported): 35% (range 8 to 66%); prevalence of CTS in both hands: 20%		High force with high flexion and CTS: $r=0.62$ High force and high extension and CTS: $r=0.29$		Participation rate: Cases selected. Occupational doctor supplied information on gender, age, years on the job, hand orientation, has or has not contracted CTS. Subjects spent 60 to 80% of their time in extension ranging from 13 to 30°. Vibratory tools more often used in tasks with high prevalence of CTS (27%) than in ones with low prevalence of CTS (13%). 92% of population were female. Non-standard data analysis approaches, no statistical testing. Examiners not blinded. Authors believe higher rate of CTS in both hands (20%) vs. dominant hand (100%) argue for non-occupational factors being more important.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Marras and Shoenmarklin 1991	Cross-sectional	40 volunteers at a highly repetitive, hand-intensive industrial jobs in 8 different plants. Half the workers were employed in jobs that had OSHA recordable repetitive trauma incidents, half the workers were in jobs with no history of recordable repetitive trauma incidents. Two subjects from 10 repetitive, hand-intensive jobs were randomly chosen to participate.	Outcome: CTS was determined from evaluation of OSHA illness and injury logs and medical records. The independent variable was exposure to jobs in which CTS had occurred previously. A low-risk job was defined as having a zero incidence rate; a high-risk job was defined as having an incidence rate of eight or more recordable repetitive trauma. Exposure: Included number of wrist motions/8-hr shift, weight of loads, handgrip types and forces, work heights, and motion descriptions. Wrist motion monitors measured in the radial/ulnar, flexion/extension, and pronation/supination planes: wrist angles, angular velocity, angular acceleration.	High-risk job: 8 incidents/ 200,000 hr exposure	Low-risk job: 0 incidents	Model for predicting high vs. low job risk based upon motion component: Position Radial/ulnar ROM: OR = 1.52 Flexion/extension ROM: OR = 1.3 Pronation/ supination ROM: OR = 1.2 Velocity Radialulnar vel: OR = 2.4 Flexion/ extension vel: OR = 3.8 Pronation/ supination vel: OR = 1.9 Acceleration Radial/ulnar accel: OR = 2.7 Flexion/ extension accel: OR = 6.1 Pronation/ supination accel: OR = 2.96	 1.1-2.1 1.0-1.7 0.9-1.6 1.3-4.3 1.5-9.6 1.2-3.2 1.5-4.9 1.7-22 1.4-6.4	Participation rate: Not reported. Examiners blinded: not stated. Confounders controlled for: Age, gender, handedness, job satisfaction. All the jobs required gloves except two-one "low-risk" and one "high-risk." Significant difference between groups with regards to age, years with the company, and trunk depth. No significant difference in job satisfaction, number of wrist movements, age, weight, stature, hand dimensions. Turnover rate: High-risk jobs: 33%; low-risk jobs: 0.5%. Grip forces were three times as great in the high-risk jobs than in the low-risk jobs. Variance between subjects within jobs accounted for a substantial percentage of total variance in wrist motion.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
McCormack et al. 1990	Cross-sectional	Textile workers: 4 broad job categories involving intensive upper extremity use. Workers randomly chosen: Sewing workers (n=562); boarding workers (n=296); packaging workers (n=369); and knitting workers (n=352) compared to other non-office workers (n=468).	Outcome: Assessed by questionnaire and screening physical examination initially by nurse. CTS diagnosed on clinical grounds of symptoms and positive Tinel's sign and Phalen's test. Physician reassessed physical findings by "standardized methods." Exposure: Assessment by observation of jobs. Exposure to repetitive finger, wrist and elbow motions assumed from job title; no objective measurements performed.	Prevalences of CTS Boarding: 0.7% Sewing: 1.2% Packaging: 0.5% Knitting: 0.9%	1.3% (non-office)	Boarding vs. non-office OR=0.5 Sewing vs. non-office OR=0.9 Packaging vs. non-office OR=0.4 Knitting vs. non-office OR=0.6	0.05-2.9 0.3-2.9 0.04-2.4 0.1-3.1	Participation rate: 91%. Physician or nurse examiners not blinded to case or exposure status (personal communication). Prevalence higher in workers with <3 years of employment. Race and age not related to outcome. Females found to have significantly more CTS than males. Job category not found to be significant, however no measurement of force, repetition, posture analysis, etc. Questionnaire asked types of jobs, length of time on job, production rate, nature and type of upper extremity complaint, and general health history. 11 physician examiners; interexaminer reliability potential problem acknowledged.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Moore and Garg 1994	Cross-sectional	32 jobs in which 230 workers were employed. This study was more an evaluation of jobs than of individuals.	Outcome: CTS identified from OSHA logs and medical records. A case required electrophysiologic testing, confirmed as abnormal by electromyographer and presence of suggestive symptoms. Exposure: Observation and videotape analysis of jobs. Force, wrist posture, grasp type, high-speed work, localized mechanical stress, vibration, cold, and work time assessed via observation of videotape. Jobs classified as hazardous or safe based on data and judgement.	13.7%	4.9%	2.8	0.2-36.7	Participation rate: Study based on records. Investigators blinded to exposure, case outcome status, and personal identifiers on medical records. Repetitiveness, "type of grasp" were not significant factors between hazardous and safe job categories. No pattern of morbidity according to date of clinic visits. Strength demands significantly increased for hazardous job categories compared to safe job categories. IR based on full-time equivalents and not individual workers, may have influenced overall results. Workers had a maximum of 32-months of exposure at plant–so duration of employment analysis limited. Average maximal strength derived from population-based data stratified for age, gender, and hand dominance. Using estimates of Silverstein's classification, association between forcefulness and overall observed morbidity was statistically significant; repetition was not. No control for confounders. No information on work history, number of unaffected workers, or exposure duration.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Morgenstern et al. 1991	Cross-sectional	1,058 female grocery cashiers from a single union. Comparison group was those who reported no symptoms. Cashiers were also compared to results from a general population study from Rochester, Minnesota (Stevens et al. 1988).	Outcome: Defined CTS as self-reported hand/wrist pain, nocturnal pain, tingling in the hands or fingers, and numbness. Exposure: Duration, use of laser scanner determined from survey (no measurements).	12%	5.4%	For a difference of 25 hr/wk: 1.88	0.9-3.8	Participation rate: 82%. Controlled for age. Information collected on age, sex, pregnancy status, work history as a checker, specific job-related tasks, use of selected drugs, history of wrist injury. In logistic regression, "Use of diuretics" significantly associated with CTS, OR=2.66 (1.00-7.04); thought to be related to fluid retention by authors. Laser scanning found not to be significant factor.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nathan et al. 1988	Cross-sectional	471 industrial workers from 27 occupations in 4 industries. Jobs grouped into 5 classes based on resistance and repetition rate.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1-cm segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Case definition did not deal with symptoms.	Prevalence of abnormal nerve conduction sensory latency:	Prevalence of abnormal nerve conduction sensory latency: Group I: 28%			Participation rate: Not reported. Analysis controlled for age and gender. No description of symptom status for defining CTS. Method of categorization of jobs and occupations not described.
				Group II: 27%		Group II vs. I: PR=1.0	0.5-2.0	Classification system is based on only repetition and not resistance as listed.
			Exposure: Jobs grouped into 27 occupations with similarities of characteristics as to type of grip, wrist position, handedness pattern, resistance, frequency, and duration of grasp and presence of vibratory and ballistic components. The 27 occupations then grouped into 5 classes. Resistance (Res.) rated from very light to very heavy; repetition rate rated from low to high.	Group III: 47%		Group I vs. III: PR=1.7	1.3-2.3	Initially excluded cases of CTS in study population, yet was supposedly identifying prevalences of CTS in exposure groups.
				Group IV: 38%		Group I vs. IV: PR=1.4	1.0-1.9	
			Group I: very light resistance and low repetition Group II: light resistance and very high repetition Group III: moderate resistance and moderately high repetition Group IV: heavy resistance and moderate repetition Group V: very heavy resistance and high repetition.	Group V: 61%		Group I vs. V: PR=2.2	1.3-3.3	For nerve conduction analysis, wrongly assumed that each hand's nerve conduction study results in an individual were independent. The 2 hands in a single individual are not independent of each other.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Nathan 1992a	Long-itudinal	315 workers using both hands (each hand analyzed separately) from four industries. These represented 67% of original group of workers from 1988 published study randomly selected from four industries (67% of original subjects) Group I: Very light resistance and low repetition Group II: Light resistance and very high repetition Group III: Moderate resistance and moderately high repetition Group IV: Heavy resistance and moderate repetition Group V: Very heavy resistance.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1-cm segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Probable CTS: Presence of any two primary symptoms (numbness, tingling, nocturnal awakening) or one primary symptom and 2 secondary symptoms (pain, tightness, clumsiness). Exposure: For this article, previous exposure classification was used from 1988 Nathan article. Jobs had been grouped into 27 occupations with similarities of characteristics as to type of grip, wrist position, handedness pattern, resistance, frequency, and duration of grasp and presence of vibratory and ballistic components. The 27 occupations then grouped into 5 classes. Resistance rated from very light to very heavy; repetition rate rated from low to high.	Group II: 19% Group III: 26% Group IV: 24% Group V: 18%	Group 1: 18%	Groups II vs. Group I: PR=1.1 Group III vs. Group I: PR=1.5 Group IV vs. Group I: PR=1.4 Group V vs Group I: PR=1.0	0.6-1.9 1.0-2.2 0.9-2.1 0.5-2.2	Participation rate: Overall: 67%; Group 3 participation rate was 59%. Examiners blinded: Not reported. Analyzed using gender, hand dominance, occupational hand use, duration of employment, and industry. 76% of participants employed in same occupational hand-use class as in 1988. A lower percentage of novice workers returned (56%) than non-novice workers (69%) for follow-up study. Analysis of "hands" instead of individual would cancel contribution of exposure effect if there was unilateral slowing. Data in table two for 1984 subjects is not the same data as presented in previous article; numbers have shifted to other groups. The significant difference seen between nerve slowing between Class 1 and Class 5 in 1988 paper is no longer significantly different. Authors note that "130 hands experienced a decrease in occupational use." No parameters given for decrease and assumption is made that both hands in an individual had similar decrease in use. With one-third of cohort missing from 1984 study, there is no way to determine if homogeneity in symptoms prevalence in 1984 and 1989 reflects absence of progression or drop-out.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Nathan 1992b	Long-itudinal	101 Japanese furniture factory workers. There were 27 managers, 35 clerical workers, 21 assembly-line or food service workers and 18 machine operators. Their NCS results were compared to 315 workers using both hands (each hand analyzed separately) from four industries. (These represented 67% of original group of workers from 1988 published study randomly selected from four industries (67% of original subjects) and are the subject of a separate table entry in this document. Group I: Very light resistance and low repetition. Group II: Light resistance and very high repetition. Group III: Moderate resistance and moderately high repetition. Group IV: Heavy resistance and moderate repetition. Group V: Very heavy resistance.	Outcome: Case defined as NCS-determined impaired sensory conduction (sensory latency). Sensory latencies assessed antidromically for eight consecutive 1 cm. segments of the nerve. A maximum latency difference of 0.4 ms or greater used to define impaired sensory conduction. Probable CTS: Presence of any two primary symptoms (numbness, tingling, nocturnal awakening or one primary symptom and 2 secondary symptoms (pain, tightness, clumsiness). Exposure: Exposure was not addressed except is assumed to be self-reported by questionnaire for the Japanese workers. The jobs were grouped into 5 classes. Resistance rated from very light to very heavy; repetition rate rated from low to high repetition.	8 cm. Sensory latency: 0.30 14 cm. Sensory latency: 0.36 Probable CTS: 2.5% Definite CTS: 2.0	8 cm. Sensory latency: 0.31 14 cm. Sensory latency: 0.45 Probable CTS: 2.0% Definite CTS: 8.3			Participation rate: For Japanese Workers: 100% Americans: Overall: 67%; Group 3 participation rate was 59%. Examiners blinded: Not reported. Analyzed using gender, hand dominance, occupational hand use, duration of employment, and industry. Analysis of "hands" instead of individual would cancel contribution of exposure effect if there was unilateral slowing. Conducted step-wise regression analysis for Probable CTS and reported that repetitions and duration of employment were protective. Cigarettes and Age were also retained in the model.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Osorio et al. 1994	Cross-sectional	56 supermarket workers. Comparison was between high and low exposure groups.	Outcome: CTS assessed via medical history, physical exam, median nerve conduction studies, and vibratory thresholds. A. CTS-like syndrome: Probable diagnosis: (1) Pain tingling numbness in median nerve distribution and (2) symptoms last >1 wk or ≥ 12 times in last year, no acute trauma or systemic disease, onset or exacerbation since working on current job. B. Median neuropathy: Sensory median nerve conduction velocity 44 m/sec or less. Exposure: Observation of jobs by ergonomist and industrial hygienist. Analysis based on categorization by job title after observation. Jobs divided into 3 categories based on the likelihood of exposure to forceful and repetitive wrist motions (low, moderate, high), years worked at this store, total years worked as checker, total years using laser scanners.	Symptoms: 63% in high-exposure; 10% in moderate-exposure group Positive NCS: 33% in high-exposure; 7% in moderate-exposure group	0% for low-exposure group 0% for low-exposure group	8.3 (for CTS-symptoms high vs. low exposure groups) 6.7 (for abnormal NCS, high vs. low exposure groups)	2.6-26.4 0.8-52.9	Participation rate: 81%. Adjusted for age, gender, alcohol consumption, and high-risk medical history. Interview and testing procedures performed by personnel blinded to case status. Skin surface temperature not controlled. Dose response for presumptive (symptoms of) exposure to forceful, repetitive wrist motion: CTS-prevalence 63% high exposure; 10% medium exposure; 0% low exposure. Dose response for prevalence of abnormal median nerve velocity: 33% high; 7% medium; 0% low. Linear regression showed significant relationship between years worked and worsening of nerve conduction (decreased nerve conduction velocity and decreased nerve conduction amplitude) adjusted for confounders (above), however small sample size.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Punnett et al. 1985	Cross-sectional	162 female garment workers; 85% were employed as sewing machine operators who sewed and trimmed by hand. Comparison: 76 of 190 full- or part-time workers on day shift in a hospital who worked as nurses or aids; lab technicians or therapists, or food service workers. Employees typing >4 hr/day excluded from comparison group. 162 female garment workers compared to 73 female hospital workers.	Outcome: CTS assessed by symptom questionnaire and physical exam. Cases defined as the presence of persistent pain (lasted for most days for one month or more within the past year); were not associated with previous injury; and, began after first employment in garment manufacturing or hospital employment. Key questions based on the arthritis supplement questionnaire of the National Health and Nutrition Examination Survey (NHANES). Median nerve symptoms (pain, numbness, or tingling) if present at night or early in the morning or met 2 of 3 criteria: (1) accompanied by weakness in pinching or gripping; (2) alleviated by absence from work for >1 wk; (3) aggravated by housework or other non-occupational tasks. Exposure: Observation of job tasks. Information on work history obtained by questionnaire. Job title used as a proxy for exposure in analyses.	18%	6%	2.7	1.2-7.6	Participation rate: 97% (garment workers), 40% (hospital workers). Controlled for age, hormonal status, and native language. Pain in the wrist and hand significantly correlated ($p<0.01$; $r=0.41$). Age distribution not significantly different metabolic disease. Symptoms of CTS showed trend by age ($p<0.01$). Prevalence of pain not associated with years of employment in garment workers. Length of employment not predictor of risk. Change in hormonal status significantly associated with CTS symptoms but negatively associated with employment in garment shop. Logistic model found garment work and age significant for symptoms of CTS. Neither metabolic disease nor change in hormonal status statistically significant risk.

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Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Schottland et al. 1991	Cross-sectional	Poultry workers (27 males, 66 females) compared to job applicants (44 males, 41 females).	Outcome: Defined as prolonged motor or sensory median latencies. No symptoms or physical exam included in case definition. Exposure: Based on current employment status at plant. No measurements made. Repetitive tasks (15 to 50 complex operations/min not rare), requiring firm grip, with wrists in flexion or extension, with internal deviations.	41% exceeding 2.2 ms for sensory latency value of median nerve on NCS (right-hand, females, corrected for age)	20% exceeding 2.2 ms for median sensory latency value (right-hand, females, corrected for age)	2.86	1.1-7.9	Participation rate: Not reported. Not mentioned whether examiners blinded to case status or exposure. Controlled for age and gender. Referents not excluded if prior employment at poultry plant; 15 referents had previous employment in poultry plant; this would result in poor selection of controls, would tend to bias results towards the null.
				24% exceeding 2.2 ms for median nerve sensory latency value on NCS (left-hand, females, corrected for age)	15% exceeding 2.2 ms for median nerve sensory latency value on NCS (left-hand, females, corrected for age)	1.87	0.6-9.8	Right-hand of female applicants who never worked in a poultry plant had significantly longer median palmar latency (MPS) on nerve conduction than referents ($p<0.04$). Symptoms of CTS not inquired. Right hand of male workers had longer MPS on nerve conduction but not significant ($p<0.07$). From Table 5-2 in paper it shows there is inadequate sample size for detecting differences in female's left-hand and male's left- and right-hand MPS. Concluded there is an elevated risk of CTS, roughly equal to risk from aging for the right hands of female workers, less risk for male both hands and female left hands.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	95% CI	Comments
Silverstein et al. 1987	Cross-sectional	652 industrial workers in 4 groups: (1) low-force, low-repetition (comparison group, n=93 males, 64 females); (2) high-force, low-repetition (n=139 males, 56 females); (3) low-force, high-repetition (n=43 males, 100 females); (4) high-force, high-repetition (n=83 males, 74 females).	Outcome: CTS determined by medical examination and interviews. Symptoms of pain, numbness or tingling in median nerve distribution. Nocturnal exacerbation; symptoms >20 times or >1 wk in previous year; no history of acute trauma; no history of rheumatoid arthritis; onset of symptoms since current job; positive modified Phalen's test (45 to 60 sec) or Tinel's sign; rule out cervical root thoracic outlet, pronator teres syndrome. Exposure: To (1) forceful, (2) repetitive, and (3) awkward hand movements assessed by EMG and video analysis of jobs. Three workers in each selected job videotaped for (at least) 3 cycles. High-force job: A mean adjusted force >6 kg (mean adjusted force = [(variance/mean force) + mean force]); Low-force job: A mean adjusted force <6 kg. High repetition = work cycles <30 sec or work cycles constituting >50% of the work cycle.	1.0 (Group 2) 2.1 (Group 3) 5.6 (Group 4)	0.6	Group 2 vs. Group 1: OR=1.8 Group 3 vs. Group 1: OR=2.7 Group 4 vs. Group 1: OR=15.5 In separate logistic models: (1) Repetitiveness: OR=5.5 ($p<0.05$) (2) Force: OR=2.9 (non-significant)	0.2-21 0.3-28 1.7-142	Participation rate: 90% response rate obtained. Controlled for age, gender, plant, years on the job. No interactions found. Jobs evaluated by investigators blinded to worker health status. Examiner blinded to medical history and exposure. Random sample of 12 to 20 active workers/job with 1 year's seniority, stratified by age and gender. Interview data included prior health and injuries, chronic diseases, reproductive status of females, recreational activities, prior job activities. No association found with wrist posture, type of grasp, or use of vibrating tool. Positive associated with age but not statistically significance. No differences in health history or recreational activities. No association with gender, or industrial plant. Negatively associated with years on the job but not statistically associated. Repetitiveness found to be stronger risk factor than force. No association with hormonal status.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Stetson 1993	Cross-sectional	Comparison of 137 asymptomatic industrial workers, 103 industrial workers with hand/wrist symptoms, and 105 control subjects randomly selected not exposed to highly forceful or repetitive hand exertions.	Outcome: Symptoms consistent with CTS defined as numbness, tingling, or burning localized to median nerve anatomic area, not caused by acute injury, and occurred >20 times in previous year. Nerve conduction studies conducted on the dominant hand; median sensory and motor, ulnar sensory, distal amplitudes and latencies were measured. Temperature monitored. Exposure: Observation and worker interviews using ergonomic checklist. One or more workers on each job were evaluated based on repetitiveness, forcefulness, mechanical stress, pinch grip, and wrist deviation, then data extrapolated to other workers performing jobs. A 3-point ordinal scale used to estimate exposure (none, some, frequent or persistent).			—	—	Participation rate: 71% seen, 16% refused, others unavailable because of layoffs, transfers, or sick leave. Industrial population randomly selected. Controlled for age, height, skin temperature, and dominant index finger circumference. Comparing the means of the nerve conduction measures, the following were statistically significantly different between: (1) the asymptomatic hand group and the controls: median sensory amplitude and distal latency, and median to ulnar comparison measures; (2) the symptomatic hand group and controls: median sensory distal latency, and median to ulnar comparison measures. Median sensory amplitudes were smaller and distal latencies longer in symptomatic compared to asymptomatic hand group. Forceful hand and upper extremity exertions were significantly different between exposed and non-exposed groups. Repetition not significantly different, but little statistical power to detect difference.

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	MSD prevalence: RR, OR, or PRR	MSD prevalence: 95% CI	Comments
Tanaka et al. 1997	Cross-sectional interview survey	Data from the Occupational Health Supplement of 1988 National Health Interview Survey conducted by the National Center for Health Statistics. Households are selected by multistage probability sampling strategy. One adult, 18 years or older, was randomly selected for interview. 44,233 interviews completed.	Outcome: Outcomes included those "Recent Workers" who worked anytime during the past 12 months (excluding armed forces). Self-reported carpal tunnel syndrome = "yes" to question: During the past 12 months, have you had a condition affecting the wrist and hand called carpal tunnel syndrome? Medically called CTS = a response of "carpal tunnel syndrome" to the question: "What did the medical person call your hand discomfort?" Exposure: By questionnaire: Did the most recent job require you to bend or twist your hands or wrists many times an hr? Did you work with hand-held or hand-operated tools or machinery.	Prevalence of self-reported CTS among recent workers: 1.47% Prevalence of medically called CTS among recent workers: 0.53%		Logistic model for medically called CTS among recent workers		Participation rate: 91.5%. Multiple logistic regression used to examine age, gender, race, exposure to vibration, and bending/twisting of the hand/wrists to odds of reporting CTS. Interactions were checked for.
						Bend/twist: OR = 5.9	3.4-10.2	
						White race: OR = 4.2	1.9-15.6	Self-reported CTS prevalence among recent workers higher in whites compared to non-whites, highest in white females.
						Female gender: OR = 2.4	1.6-3.8	
						Vibration: OR = 1.85	1.2-2.8	When vibration was not in the model the bend/twist OR = 5.99. When bend/twist is not in the model, vibration OR = 3.00.
						BMI ≥25: OR = 2.1	1.4-3.1	
						Cigarette use: OR = 1.6	1-2.5	Major limitation is CTS is based on self-reports without medical validation.
						Age ≥40: OR = 1.3	0.2-1.9	No temporal relationship could be found between reported CTS and the reported occupation/industry or exposure to bending/twisting of the hand/wrist.
						Annual income ≥$20,000: OR = 1.5	1-2.4	
						Education >12: OR = 1.2	0.8-1.8	

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Table 5a–5 (Continued). Epidemiologic studies evaluating work-related carpal tunnel syndrome (CTS)

Study	Study design	Study population	Outcome and exposure	MSD prevalence: Exposed workers	MSD prevalence: Referent group	RR, OR, or PRR	95% CI	Comments
Weislander et al. 1989	Case-control	34 male CTS patients, each matched to 2 other hospital referents (drawn from among other surgical cases, one referent had been operated on for gall bladder surgery and the other for varicose veins) and 2 population referents (from a general population register and telephone directory) (total comparison group = 143 males).	Outcome: CTS diagnosed clinically by a hand surgeon, confirmed by electro-diagnostic studies. Exposure: To vibrating tools, repetitive wrist movements, and loads on the wrist assessed via telephone interview using a standardized questionnaire. The degree of exposure was evaluated both with regard to the total number of work years and the average number of exposed hr a wk. Repetitive movements classified independently by physician interviewer and occupational hygienist. Exposure to repetitive wrist movements was considered to exist if they agreed.	—	—	Cases compared to all referents (hospital- and population-based): Vibrating tool use: OR = 3.3 Repetitive wrist movement for >20 years: OR = 2.7 Loads on the wrist: OR = 1.8 Cases compared to population referents alone: Vibrating tool use: OR = 6.1 Repetitive wrist movement for >20 years: OR = 4.5 Loads on the wrist: OR = 2.7 Obesity: OR = 3.4	1.6-6.8 1.3-5.4 1.0-3.5 2.4-15 2-10.4 1.3-5.6 1.2-9.8	Participation rate: 93%. Referents matched for gender and age (±3 years.), hospital referents for year of operation. Hospital referents and population referents statistically different comparing: use of vibrating tool, repetitive movements of wrist, workload on wrist, obesity. Hospital-based population may not reflect industrial workplace. Interviewers not blinded to case status. Elevated OR for repetitive movements of the wrist only statistically significant for the category '>20 years.' Odds ratios (OR) for any of the three diseases (thyroid disease, diabetes, rheumatoid arthritis) found to be statistically significant among cases with CTS compared to 143 referents; OR = 2.8 (1.0-7.6). ORs tended to increase with increasing number of risk factors present. One factor, OR = 1.7 (0.6-4.4); two factors, OR = 3.3 (1.2-9.1); >two factors, OR = 7.1 (2.2-22.7). Obesity is >10% above reference weight.